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Spectral-Based Volume Sensor Testbed Algorithm Development, Test Series VS2

Daniel A. Steinhurst

Nova Research, Inc.
Alexandria, VA

James A. Lynch
Daniel T. Gottuk

Hughes Associates, Inc.
Baltimore, MD

Jeffrey C. Owrutsky
Herbert H. Nelson
Susan L. Rose-Pehrsson

Chemical Dynamics and Diagnostics Branch
Chemistry Division

Frederick W. Williams

Navy Technology Center for Safety and Survivability
Chemistry Division

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Daniel A. Steinhurst,* James A. Lynch,† Daniel T. Gottuk,† Jeffrey C. Owrutsky, Herbert H. Nelson, Susan L. Rose-Pehrsson, and Frederick W. Williams‡

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14. ABSTRACT

The Advanced Volume Sensor Project is one element of the ONR Advanced Damage Countermeasures FNC program. The Volume Sensor Project is developing new methods for remote situational awareness and damage control event detection using conventional video cameras and other techniques. The Spectral-Based Volume Sensor (SBVS) Testbed uses a suite of single-element optical detectors operating outside the visible region. Event detection algorithms were developed to make use of the data generated by the SBVS Testbed. These algorithms detect flaming and smoldering sources both within and outside the SBVS Testbed's field of view (FOV). A positive nuisance classification algorithm was also developed for arc welding and similar nuisance events, which detected all welding events with extremely few false alarms. The developed algorithms were tested against data collected during the Volume Sensor Test Series 2, July to November 2003. Comparable performance to COTS OFDs was achieved for FOV flaming sources, and superior performance was demonstrated for partially or completely obscured flaming sources.

15. SUBJECT TERMS
Fire detection; Optical flame detection; Volume sensor; Remote sensing; Smoke detection; Arc welding detection; Damage control; Damage countermeasures

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CONTENTS

CONTENTS (CONT.)

FIGURES

TABLES

FILE LISTINGS

ACRONYMS USED

Acronym	Definition
!	"Not," Indicates the opposite of the symbol it is placed in front of, e.g. !FOV indicates not in the field of view.
AC	Alternating Current
ADC	Advanced Damage Countermeasures Program
B/W	Black and White
BB	Broadband
CCD	Charge Coupled Device
COTS	Commerical, Off-The-Shelf
CVN21	Future Aircraft Carrier, CVN 21. Formerly known as CVNX
CVNX	CVN21 Fire Threat to Ordnance Test Series 2
CVNX	Carrier Vehicle, Nuclear Experimental
DAQ	Data Acqusition (Hardware)
DataLogger	Data acqusition software written by NRL Code 6111
DC	Damage Control
DC	Direct Current
DD(X)	DD(X), 21st Century Destroyer. The Navy's future multi-mission surface combatant.
F	Flaming Source
FA	False Alarm
FNC	Future Naval Capability, sponsored by ONR
FOV	Field Of View
FPDataLogger	Data acqusition software written by NRL Code 6111
FWHM	Full Width, Half Maximum
IF	Interference Filter, a filter which passes wavelengths at a center wavelength with a bandwidth given as FWHM
IR	Infrared. In this document, IR refers to the mid-IR, around 4.3 µm.
L	Left
LP	Longpass (filter), passes wavelengths greater than a cutoff wavelength
LWVD	Long Wavelength-response Video Detection
MD	Maryland
MV	Machine Vision
N	Nuisance Source
NIR	Near Infrared
NRL	U.S. Naval Research Laboratory
OFD	Optical Flame Detector
OH	OverHead
ONR	Office of Naval Research
PC	Personal Computer
PC	Principal Component
PCA	Principal Component Analysis

ACRONYMS USED (CONT.)

Acronym	Definition
P_{corr}	Probabilty / Percentage of Correct Classification (# Correct / # Total)
PD	PhotoDiode
P_d	Probabilty / Percentage of Detection (# Correct Detections / Total of Sources)
P_{fa}	Probabilty / Percentage of False Alarm (# FAs / Total # of Sources)
R	Right
RT	Room Temperature
S	Smoldering Source
SBVS	Spectral-Based Volume Sensor
SFA	Smoke and Fire Alert, a VIDS product of Fastcom Technology, S.A.
SigniFire	a VIDS product of axonX, LLC
SP	Shortpass (filter), passes wavelengths less than a cut-off wavelength
T	Transitioning Source
TC	ThermoCouple
Trans	Transitioned
UV	Ultraviolet
VAC	Alternating Current Volts
VDC	Direct Current Volts
VID	Video Image Detection
VID(S)	Video Image Detection (System)
VS	Volume Sensor
VS1	Volume Sensor Test Series 1
VS2	Volume Sensor Test Series 2
VS2A	Volume Sensor Test Series 2 - Tests VS2-001 through -188
VS2B	Volume Sensor Test Series 2 - Tests VS2-189 through -253
VS3	Volume Sensor Test Series 3
VSD-8	Visual Smoke Detection System, a VIDS product of Fire Sentry Corp.

Spectral-Based Volume Sensor Testbed Algorithm Development, Test Series VS2

1.0 INTRODUCTION

The Advanced Volume Sensor Project is one element of the Office of Naval Research's Future Naval Capabilities program, Advanced Damage Countermeasures. This program seeks to develop and demonstrate improved damage control (DC) capabilities to help ensure that the recoverability performance goals for new ship programs, such as the CVN21 and the DD(X) families of ships, can be met with the specified manning levels and damage control systems. Using a multi-sensory approach, the Naval Research Laboratory (NRL) is developing new detection capabilities for DC in the shipboard environment. Conventional surveillance cameras, which are currently being incorporated into new ship designs, provide the basis for the Volume Sensor (VS) project. Video Image Detection (VID) is an emerging technology for the remote detection of events within the camera's field of view (FOV) by applying image analysis, or machine vision, techniques to the video image. Various spectral and acoustic systems are being developed in combination with the video image detection technologies to produce an overall sensor system that is able to provide a broad range of situational awareness for the sensor's entire field of view. The use of remote sensing techniques removes the constraint of typical smoke and fire detection systems that rely on diffusion of gases and particles to the detector. A Volume Sensor Prototype is under development at the Naval Research Laboratory to provide an affordable, real-time, robust, and remote detection sensor system that will detect and classify damage control conditions such as fire, explosions, pipe ruptures, and compartment flooding. The Volume Sensor Prototype will also generate alarm notifications for action by the Damage Control Assistant and other available damage control systems based on the detected event.

The goal of the Spectral-Based Volume Sensor (SBVS) Component is to develop methods for detecting fire, smoke, and other hazardous conditions using optical methods outside the visible region of the electromagnetic spectrum. The sensors developed within the SBVS Component are intended to be used in conjunction with and to augment the performance of the core VID technology of the Volume Sensor. The VID systems are generally better at identifying smoke than fire, so a primary goal of the SBVS Component is to provide better detection for flame and fire. An important constraint in the Volume Sensor Program is that the eventual system must be affordable with a target unit cost well below $1000. This precludes the use of more obvious solutions such as mid-infrared (IR) cameras because the per-unit price is too high (> $10,000 per unit). Two avenues have been pursued in parallel within the SBVS Component. One approach employs long wavelength video detection (LWVD), emphasizing the benefits of spatial resolution and near infrared imaging afforded by readily available, inexpensive video cameras. Descriptions and results of the LWVD system are provided in other reports [for example, Reference 1]. The second avenue utilizes single-element detectors operating in several narrow spectral regions from the IR to the ultraviolet (UV) that correspond to peak flame emissions.

The single-element detectors come from two sources: commercial off-the-shelf (COTS) optical flame detectors (OFDs), which contain one or more single-element detectors; and single-element detectors assembled in-house at NRL from commercially available detectors, detector elements, and interference filters (IFs). The COTS OFDs were modified to allow access to

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diagnostic outputs that made the raw data from each sensor available in addition to the final OFD alarm state. These modifications permitted evaluation of each sensor element independently from the overall OFD operation in order to determine whether including that element would improve the VS Prototype performance. The OFDs used were both UV/IR OFDs, in which the detected regions are at ~4.3 μm where CO_2 emits strongly and in the UV region (185-260 nm).

For the second element of the SBVS Testbed, sensors were constructed in-house at NRL for narrow spectral bands that correspond to atomic or molecular emission within flames. These spanned a wide spectral region including the IR, visible, and UV. Some of these were configured to detect at the same wavelengths as a single detector within the COTS OFDs for comparison and as a parallel effort in case access to the raw data from the OFDs could not be achieved. Other in-house detectors were constructed for wavelengths not commonly used for indoor fire detection. Atomic emission of potassium at 766 nm has been reported for remote, satellite-based fire detection [2] and this concept was adopted for use in the SBVS Testbed. As a decision guide for possible detection wavelengths, we collected UV/visible emission spectra of several fire sources. These indicated that fires also have appreciable emission at the 589 nm sodium lines, so a detector for these wavelengths was included as well as a detector at a nearby guard band to minimize false alarms.

This report details the analysis of data collected from the VS Spectral Component's SBVS Testbed [3,4] following the Volume Sensor 2 (VS2) Test Series [5,6], conducted at the Hughes Associates facility in Baltimore, MD from July to November, 2003. During the VS2 Test Series, the SBVS Testbed collected and recorded data from a suite of sensors (the SBVS Testbed). These data were not analyzed in real time, no feedback was provided to the test team, and no information was transmitted to any nascent VS Prototype [7]. A primary goal of the VS2 test series and the subsequent analysis described here is to develop algorithms for the VS Prototype. The VS Prototype and the individual components were evaluated during the Volume Sensor Test Series 3 (VS3), conducted on the ex-USS *Shadwell* [8], July 6 – 16, 2004 [9,10]. Further testing and evaluation is ongoing [11].

The SBVS Testbed collected test data throughout the VS2 Test series. After the fact, the data were preprocessed (background subtracted and normalized). A statistical analysis, Principle Component Analysis (PCA), was conducted using the preprocessed data to identify unique, composite features to use as the basis for developing event detection algorithms. One composite "observable" and five damage control event detection algorithms were identified. Including additional rule-based conditions empirically based on the source spectral characteristics augmented the algorithms. The algorithms were significantly improved by testing and optimizing them, e.g., by varying threshold (channel amplitude) and persistence (time constant) criteria. These algorithms have since been incorporated into a data collection program to generate a complete spectral-based damage control system. This system has further been integrated into the overall Volume Sensor Prototype currently undergoing testing.

The organization of this report is as follows. Section 2 briefly discusses the experimental details of the VS2 Test Series. More information can be found in References 5 and 6. Section 3 gives a very brief introduction to the PCA methodology used. Section 4 discusses the preparation of the data for analysis and Section 5 discusses the development of the SBVS event algorithms. Section 6 covers the optimization of the SBVS event algorithms and Section 7 gives the final, optimized results for the SBVS event algorithms. Sections 8 and 9 cover the final discussion and conclusions of this work, respectively. Sections 10 and 11 give acknowledgement to the people

and references involved in the support of this effort. Appendices A through D provide portions of the supporting materials, test data, and algorithm results that the reader may find useful in the reading of this text. The complete collection of supporting information is available on the attached CD. See the CD Readme file for further information.

2.0 VS2 TEST SERIES EXPERIMENTAL SETUP AND SOURCE INFORMATION

2.1 Test Compartment Location and Design

All VS2 Test Series tests were conducted at the Hughes Associates, Inc. facility in Baltimore, MD during the summer and fall of 2003. Two test compartments were outfitted for this test series. The first (Compartment 1) was built to simulate the medium size compartment on board the ex-USS *Shadwell* that was used for the VS1 and CNVX Test Series in April 2003 [12,13]. Lighting and obstructions were added [5] to simulate a general shipboard space. The second compartment (Passageway) was designed to simulate a typical shipboard passageway in terms of dimensions and sight lines. See the VS2 Test Series Test Plan and Report for additional details [5, 6].

2.2 Test Source Location and Types

Data were collected for several different types of fire and nuisance sources at eleven different test locations throughout the test space. The selection of sources was based on the previous studies conducted within the VS program [12,13]. Table 2.1 lists the source locations used. Tables 2.2 and 2.3 lists the different fire and nuisance source types used, respectively. Figures 2.1 and 2.2 show schematics of Compartment 1 and the Passageway with the source locations indicated.

Table 2.1 — Location of Fire or Nuisance Sources in Reference to the Aft and Port Bulkheads

Location number	**From Aft (m)**	**From Port (m)**	**Height above deck (m)**
1	1.42	1.78	0.00
2	3.25	1.22	0.00
3	1.52	1.52	0.00
4	1.42	4.24	0.00
4A	1.42	4.24	0.76
5	7.62	1.52	0.00
6	7.62	4.58	0.00
7	5.41	3.30	0.00
Passageway Location	**Aft to forward (m)**	**Port to starboard (m)**	**Deck to overhead (m)**
8	0.61	7.32	2.74
9	0.00	7.32	0.00
10	0.00	2.74	0.00

2.3 – NRL SBVS Testbed

The overall concept of the Volume Sensor and the experimental details of the SBVS Testbed have been briefly outlined in earlier sections of this document and discussed in greater detail elsewhere [1,3,4,13]. The SBVS Testbed is composed of several optical detectors that

operate in discrete portions of the electromagnetic spectrum, generally outside the visible region. The goal is to use spectrally rather than spatially resolved information to provide both detection and classification information not generally available to the standard video cameras and VID systems which are being evaluated within the VS program. This additional information would then be used to augment the performance of the VID systems, perhaps in conjunction with the enhanced spectral range of the long wavelength response cameras and VID algorithms of the NRL LWVD system [1].

The SBVS Testbed approach with single element sensors is to detect atomic, molecular, and broadband emissions that are characteristically produced by flames. Typical flame emission spectra can be found in the literature and in Reference 3. The technique is essentially an extension of the approach employed in commercially available OFDs, which typically include several elements operating in the IR or UV. The SBVS Testbed consists of two COTS OFDs with IR and UV detectors as well as in-house detectors operating at various wavelengths ranging from the IR to the UV. The OFDs (Sensor Electronics EyeSpy 502-09 and Vibrometer OmniGuard 860) have been modified so that the outputs of each individual sensor element can be monitored and recorded independently in addition to the unit's internal alarm status. The sensors that were configured in-house are intended to provide some redundancy with the commercial systems (IR at 4.3 μm and UV at 260 nm) as well as to explore the prospects of monitoring emission wavelengths not commonly used for flame detection. These sensor elements consist of a narrowband interference filter (typically 10 nm full width, half maximum (FWHM)) placed in front of an appropriate detector, for example, a photodiode (PD) for the near infrared (NIR) or visible region and a photomultiplier tube (PMT) in the UV.

Table 2.2 — List of Fire Sources Used During Testing

No.	Fire Source ID	Description
1	Smoldering Cable Bundle	A bundle of cable consisting of 5 pieces, each 0.3 m (1 ft) in length (Monroe Cable Co., LSTSGU-9, M24643/16-03UN XLPOLYO), surrounding one 500 W cartridge heater (Vulcan, TB507A) was used to create a smoldering source. The heater was energized using a variable transformer set at 96 VAC (80% of 120 V max).
2	Flaming Cardboard Box	A total of four boxes 0.26 m x 0.26 m x 0.11 m were loosely filled with crumpled brown paper (1.1 m x 0.6 m) and positioned in two rows side by side with a 2.5 cm flue space between the two rows. The boxes were oriented in each row end to end so that the 0.26 m x 0.26 m sides faced the opposite row across the flue space. Butane lighter was used to light a bottom corner of a box in the flue space so that flames propagated up the flue space and involved both boxes.
3	Flaming Cardboard Box (plastic)	A total of four boxes 0.26 x 0.26 x 0.11 m were loosely filled with plastic bubble wrap (1.1 m x 0.6 m) and positioned in two rows side by side with a 2.5 cm flue space between the two rows. The boxes were oriented in each row end to end so that the 0.26 x 0.26 m sides faced the opposite row across the flue space. Butane lighter was used to light a bottom corner of a box in the flue space so that flames propagated up the flue space and involved both boxes.
4	Smoldering Bag of Trash	One bag 60 cm x 57.5 cm, 32.2 L, 15 μm filled with ordinary trash obtained from the office (printer paper, paper towels, plastic, mailing packs, envelopes) was used with one 500 W cartridge heater (Vulcan, TB507A) energized to 120 VAC. The heater was placed on top of a piece of gypsum board beneath the closed bag.
5	Smoldering Trash Can	One 60 cm x 57.5 cm, 32.2 L, 15 μm bag was filled with ordinary trash obtained from the office (printer paper, paper towels, paper cups) and placed in a metal trash can measuring 30.5 cm deep x 40.6 cm x 22.9 cm. A single piece of 8½" x 11" paper is crumpled into a ball making a pocket and placed on top of the open bag of trash. A lit cigarette is then placed in the center of the pocket of the crumpled paper ball and left to smolder.
6	Smoldering Wire	Two pieces of 1 m long wire was powered in parallel at 6 VAC (with no current limit) for 1 minute. The wire was constructed of 10, 0.1 mm strands, insulated with PVC to a radial thickness of 0.3 mm, with a cross-sectional area of 0.078 mm^2. The test follows British Standard BS6266.
7	Smoldering Printed Circuit Board	The test was designed to replicate electronic fires involving circuit boards. A FR-4 substrate board was energized at 9 V, 8.5 amps to produce smoldering substrate and a traveling arc between two 50 mil wide copper tracks, spaced 50 mil apart.
8	Smoldering Laundry	Three miscellaneous pieces of clothing (cotton) were folded and piled one on top of another. One 500 W cartridge heater (Vulcan, TB507A) powered at 120 VAC was placed in the middle of the pile and set to 96 VAC (80% of 120 V max).
9	Smoldering Mattress and Bedding	One 0.3 m x 0.3 m section of Navy mattress (MIL-M-18351F(SH), 11.4 cm thick Safeguard polychloroprene foam core covered with a fire retardant cotton ticking) was under a loose pile of bedding, including one polyester batting, quilted mattress pad (Volunteer Blind Industries, GS-07F-14865, DDD-P-56E), one sheet (Federal Specification DDD-S-281) and one brown bed spread (Fed Spec DDD-B-151) (each 0.6 m x 0.6 m). One 500 W cartridge heater (Vulcan, TB507A) energized at 120 VAC was located between the bedding and the mattress ticking.
10	Smoldering Computer Monitor	A 15-inch standard monitor was exposed to an internal heat source. One 500 W cartridge heater (Vulcan, TB507A) was inserted into a 1.6 cm hole at the bottom corner of the monitor (either front or back). The cartridge heater was energized to 80% of the 120 VAC supply.
11	Flaming Trash Can	One 60 cm x 57.5 cm, 32.2 L, 15 μm bag was filled with ordinary trash obtained from the office (printer paper, paper towels, paper cups) and placed in a metal trash can. The open bag of trash was lit at the top with butane lighter.
12	Smoldering Trash Can	One 60 cm x 57.5 cm, 32.2 L, 15 μm bag was filled with ordinary trash obtained from the office (printer paper, paper towels, paper cups) and placed in a metal trash can measuring 30.5 cm deep x 40.6 cm x 22.9 cm. A cigarette was then placed in the folds of a loosely crumpled up piece of paper on top of the open bag of trash.
13	Flaming Mattress and Bedding	A Butane lighter was used to ignite the top bedding material in the corner of the mattress and bedding setup.

Table 2.3 — List of Nuisance Sources Used During Testing

Number	Nuisance Source ID	Description
1	Man working in compartment	A single man working in view of the cameras. Duration is test dependant.
2	People Working in compartment	Multiple people working in view of the cameras. Duration is test dependant.
3	Waving Materials	Waving a white t-shirt. The material was waved/shaken by a person moving through the space and stopping in front of each camera for a short period of time.
4	Cigarette Smoke	Four smokers in the space, each smoking a single cigarette
5	Spray Aerosol	Five second spray intervals at multiple locations in the test space. Two aerosols were used: 1) Old Spice High Endurance Anti-perspirant and deodorant (pure sport). 2) Lysol disinfectant spray.
6	Toaster: Overdone Toast	A Magic Chef model number N-10, 120 VAC, 60 Hz, 1500W Toaster with 4 slices of white bread toasted at the darkest setting for three cycles.
7	Welding	Welding of two pieces of steel using an arc welder operating at 150 amps using 7018 rods.
8	Grinding Unpainted Steel	Grinding metal with a 3½” power hand grinder for approximately 5 minutes.
9	Sunlight	Open outside rollup delivery door to let sunlight shine in through the open test compartment door (D1) and observation windows. The window was located on the starboard bulkhead 3.10 m from the aft bulkhead. The window measured 1.45 m high and 1.19 m wide. The window began at deck level and was usually cover by a square piece of drywall when the sunlight tests were not being conducted.
10	Flash Light	Person carrying a flashlight and shining it towards the various sensors
11	Flash Bulb	Person with camera flash in space taking pictures of the various sensors

The SBVS Testbed was installed on a metal shelf (~ 30 cm deep x 0.9 m wide) in each of the test compartments. In Compartment 1, the SBVS Testbed was located on the starboard bulkhead 0.8 m below the overhead, 3.9 m from the aft bulkhead. In the passageway, the SBVS Testbed was positioned above the doorway at a height from deck of 2.1 m, centered on the starboard bulkhead. The instrumentation on the SBVS Testbed is identified in Table 2.4. Other components of the VS Prototype were also installed to collect data during these tests. These additional systems are also listed in Table 2.4. Refer to the VS2 Test Plan [5] and Test Report [6] for further details on these other systems.

2.4 – Test Protocol

The general test procedure was to synchronize the internal clocks of all instrumentation, then to initiate data collection for all systems. Background data were collected for a minimum period of 120 seconds. After the background period, the source would be initiated and the time of day recorded. The test source would be allowed to evolve and the test was terminated after all systems had reached an alarm state or after conditions were deemed to have reached a maximum or steady state level, such that no further detection alarms were anticipated. The test space was then ventilated until all detection systems returned to normal background level. Any additional events, such as a smoldering source transitioning to a flaming source, are also recorded along with the corresponding time of day.

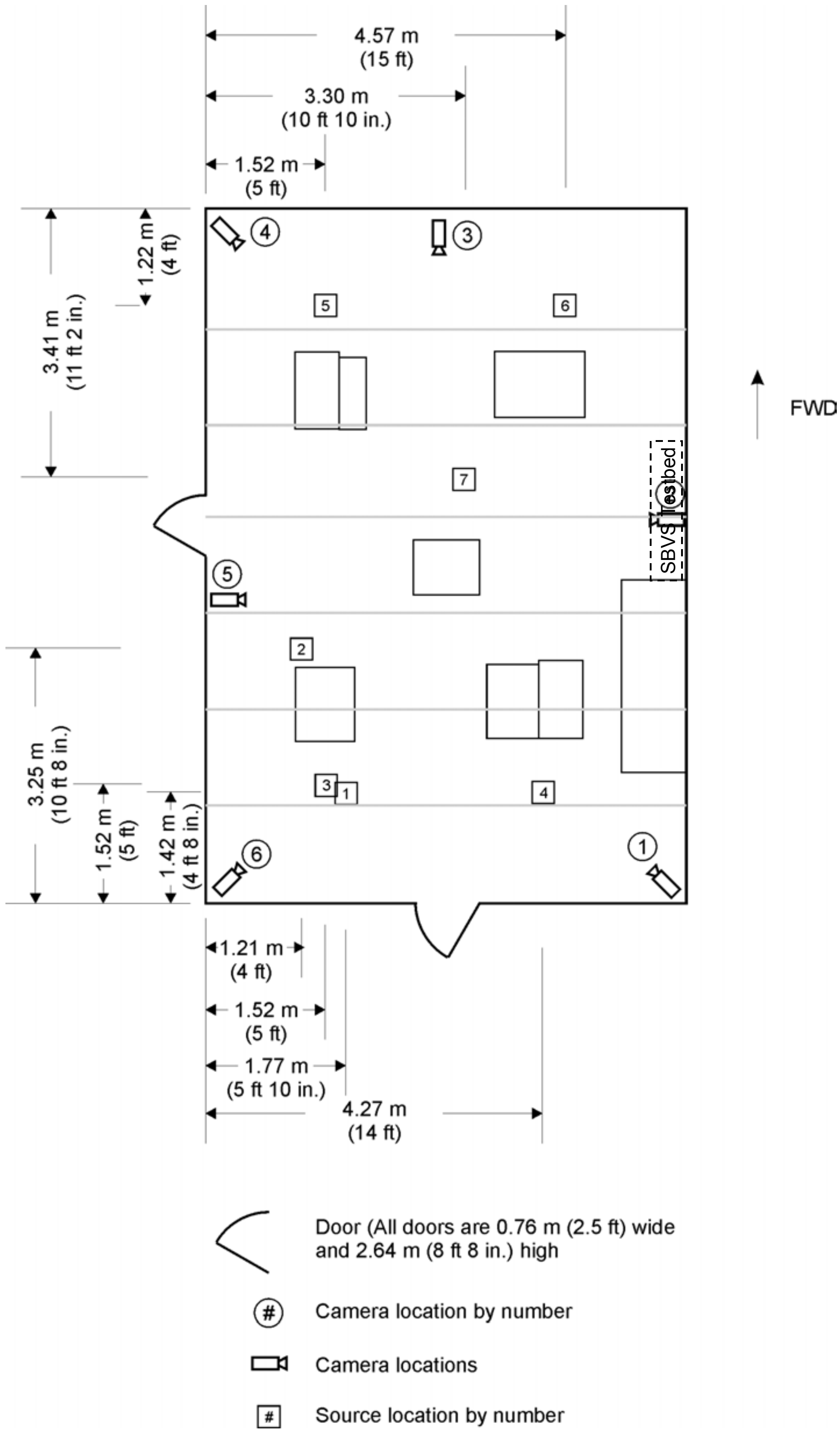


Figure 2.1 – Schematic of Compartment 1

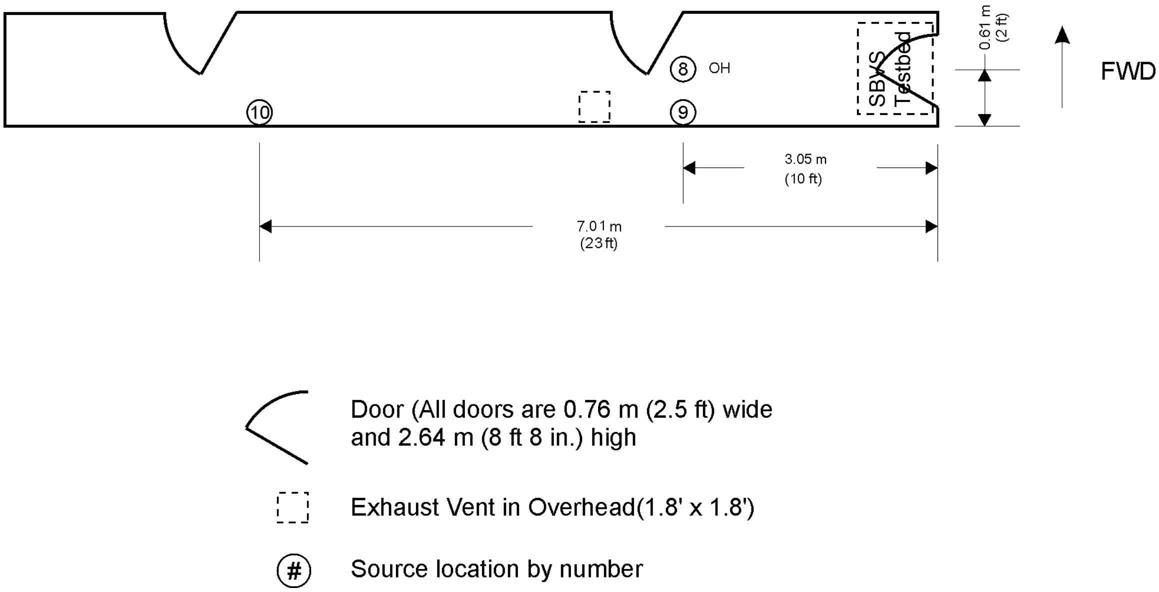


Figure 2.2 – Schematic of Passageway

Table 2.4 — VS2 Fire Detection Equipment and Sensors

Manufacturer	Model and/or Number	Description
COTS VIDS		
Fire Sentry	VSD-8	Video smoke detection system
Fastcom	Smoke & Fire Alert (SFA)	Video flame and smoke detection system
axonX	SigniFire	Video flame and smoke detection system
Point Detectors		
EST	SIGA-IPHS SIGA-IS SIGA-PS	Multi-Sensor Detector Ionization Smoke Detector Photoelectric Smoke Detector
Notifier	SDX-751 FSI-751	Photoelectric smoke detector Ionization smoke detector
Spectral-Based Volume Sensor Testbed		
Vibrometer	OmniGuard 860	UV/IR OFD
Sensor Electronics	EyeSpy 502-09	UV/IR/BB OFD
UDT Sensors	UV100	Si Photodiodes with IF (3x, 5900, 7665, 10500 Å)
Judson Technologies	J14TO Series, Model PE-0-51	4.3 micron RT IR
Hamamatsu	R446	PMT with 2600 Å IF
Hamamatsu	R446	PMT with 3070 Å IF
Long Wavelength Cameras		
CSi-SPECO (0.02 Lux)	CVC-130R	B/W Bullet camera with IF (LP or SP)
Sony (0 Lux)	DCR-TRV 27 or DCR-PC-101	Color camcorder with IF (LP or SP)
NRL	LWVD System	NRL prototype Machine Vision Event Detection System, available for test VS2-95 and above
Lorex	VQ-2120	8500 Å NIR Illuminator
UV/VIS Spectrometer		
Ocean Optics	HR2000	UV/VIS Fiber Spectrometer
Acoustic Sensors		
Bruel & Kjaer	4141	Extended-range microphone (3-40000 Hz)
Shure	KSM 141	Standard microphone (20-20000 Hz)

3.0 PRINCIPAL COMPONENT ANALYSIS

3.1 Introduction

A general discussion of Factor Analysis and Principal Component Analysis (PCA) is beyond the scope of this document. A good reference for the theory and application of PCA to chemically relevant systems is Reference 14. An electronic textbook on the subject is also available [15].

Factor Analysis is primarily used for two purposes. The first purpose is to identify structure or organization between variables within a data set. The second purpose is to then construct composite variables that reduce the total number of parameters required to completely describe the data set. The basis of PCA evaluation of a data set is the generation of one or more reduced variables that most efficiently describe the variability of the data set. The value of each new variable (known as a "score") is actually a linear combination of the original variables. Each score has a corresponding "loadings" vector that describes this linear combination. Thus, each score can be viewed as a projection of the original data into a reduced data space defined by a loadings vector. Each loadings vector describes an underlying factor, or principal component in the data. The calculation of loadings for an arbitrary number of factors is an eigenvalue/eigenvector problem in which the loadings vectors are the eigenvectors. Since the eigenvector for each successive factor is constructed using residual information from previous factors, they are necessarily orthogonal and account for less and less of the total variation contained within the original data. An analogous method from spectroscopy would be normal-mode analysis. This method is also known as a variance maximizing rotation or a Varimax rotation.

3.2 Data Requirements

PCA generates a series of eigenvectors with each sucessive eigenvector accounting for less and less of the total variation within the data set. The normalization of the individual data channels is important for performing an unbiased PCA analysis. If the data are not normalized, issues such as the masking of a significant change in a small amplitude signal by a small relative change in a large amplitude signal could occur. Also, the data density should be uniform across the data channels to eliminate any bias due to any variation in the data density. The normalization and data density downsampling processes used in this work are discussed in Section 4 of this document.

3.3 Methodology Applied to Test Data Analysis

To fully explore all of the proposed experimental parameters set out for the VS2 Test Series, over 250 separate tests were conducted. To reduce the amount of data to be analyzed for SBVS event algorithm development to a tractable size, a series of candidate tests were selected for analysis. The thirty-three candidate tests, listed in Table 3.1 below, were selected to be representative of the variety of sources and nuisances tested in this test series while keeping the number of tests manageable. The tests were also selected to allow for comparison between similar sources both in and out of the SBVS Testbed's field of view (FOV). In addition, for smoldering sources a selection of transitioning and non-transitioning to flaming sources were

Table 3.1 — VS2 SBVS Testbed Candidate Tests

Sources				
VS2 Test #	**SigmaPlot DL Filename**	**Source Type**	**In FOV? [a]**	**Transitioned?**
007	Jul232003_112202.JNB	Flaming Bedding		Yes
019	Jul292003_095917.JNB	Flaming Boxes w/ Paper Filling		Yes
010	Jul232003_151943.JNB	Flaming Boxes w/ Paper Filling	Yes	Yes
198	Nov102003_143355.JNB	Flaming Boxes w/ Plastic Filling	Yes	Yes
194	Nov102003_094821.JNB	Flaming Cable Bundle		Yes
217	Nov142003_101459.JNB	Flaming Cable Bundle	Yes	Yes
120	Sep182003_133353.JNB	Flaming Trash Can		Yes
121	Sep182003_141133.JNB	Flaming Trash Can	Yes	Yes
165	Oct232003_165200.JNB	Smoldering Cables		
223	Nov142003_154727.JNB	Smoldering Cables	Yes	Yes
181	Oct282003_111335.JNB	Smoldering Circuit Boards		
177	Oct272003_154425.JNB	Smoldering Laundry		Yes
114	Sep082003_182121.JNB	Smoldering Laundry (transitioned)		Yes
064	Aug202003_151703.JNB	Smoldering Laundry	Yes	
096	Sep042003_164111.JNB	Smoldering Laundry (transitioned)	Yes	Yes
168	Oct242003_095036.JNB	Smoldering Mattress		Yes
158	Sep302003_151718.JNB	Smoldering Monitor		Yes
178	Oct272003_165406.JNB	Smoldering Trash		Yes
180	Oct282003_104335.JNB	Smoldering Wire		
102	Sep052003_154457.JNB	Flaming Wood Crib		Yes
			Total	**20**
Nuisances				
VS2 Test #		**Source Type**	**In FOV?**	**Transitioned?**
133	Sep242003_104803.JNB	Aerosol	?	
152	Sep302003_103617.JNB	Toast		
136	Sep242003_140145.JNB	Toast, Burnt		
155	Sep302003_134829.JNB	Cutting Steel	Yes	
156	Sep302003_141409.JNB	Cutting Steel		
209	Nov122003_160146.JNB	Flash Bulb	?	
207	Nov122003_152802.JNB	Flash Light	?	
131	Sep242003_100748.JNB	People Working	?	
141	Sep252003_065636.JNB	Sunlight		
212	Nov132003_082340.JNB	Sunlight		
145	Sep302003_082827.JNB	Waving White Shirt	?	
137	Sep242003_144239.JNB	Welding	Yes	
154	Sep302003_132510.JNB	Welding (Stick)		
			Total	**13**

[a] A result of "?" in the "In FOV?" column indicates that the source was either moving about the compartment during the test or the precise location of the source as a function of time is unknown.

selected. Columns 1 and 2 of Table 3.1 indicate the VS2 test number for each test and the corresponding SBVS Testbed data root file name.[1] Column 3 lists the Source Type, and Columns 4 and 5 indicate whether or not each test was within the FOV of the SBVS Testbed and if the source transitioned during the test (defined as yes for flaming sources), respectively.

The three raw data files for each candidate test were combined into a common file format, normalized, and baseline subtracted as described in Section 4. The data from each test was then converted into the Oasis montaj database (.gdb) format for PCA. Oasis montaj (v5.1.8) is a geophysics and geochemistry package produced by Geosoft, Inc. that has a PCA module (Chimera DPA) available. Any software package capable of PCA would be sufficient, but Oasis montaj is familiar to the authors and supports large scale batch processing of data, which is a concern for this project. PCA was then conducted on each candidate test's data. A number of eigenvectors and loading factors were extracted for each test. In Section 5, the resultant eigenvectors and weighting will be presented and discussed.

4.0 DATA PREPROCESSING

4.1 Baseline Correction and Normalization

A slightly expanded version of the original SBVS Testbed [4] was originally fielded for the VS2 Test Series along with the original data acquisition program, DataLogger. A new Ethernet-based, distributed data acquisition system (National Instruments, FieldPoint) was constructed and new software, FPDataLogger, was installed after test VS2-188. This corresponded with testing moving to the Passageway. While functionally the same, the two versions had minor differences in the output file configuration. Tests VS2-001 through VS2-188 are therefore classified as VS2A tests, while tests VS2-189 through VS2-253 are classificed as VS2B tests. The generation of a common data set allowed for all VS2 data to be analyzed with the same processing configuration once converted. The data for each test were stored in three separate files, one for each source device: 1) the data acquisition (DAQ) hardware; 2) the OmniGuard 860 OFD, and 3) the EyeSpy 502-09 OFD. The data from all three files were combined into a single common format data file. The data collection rate for the DAQ hardware was 10 Hz, while the rest of the data were collected at 1 Hz. During the combining process, the DAQ data were down-sampled to 1 Hz by only including one out of ten readings after synchronizing the start times between the three data files. Example data files are given in Appendix A.

Normalization is important for performing an unbiased PCA analysis. If the data are not normalized, issues such as the masking of a significant change in a small amplitude signal by a small relative change in a large amplitude signal could occur. Normalization consists of two stages, background subtraction and application of a scaling factor to each data channel. The standard test protocol [5] is to accumulate at least two minutes of quiet background data prior to source ignition. The first twenty seconds of each data file were used to determine the baseline values for all channels. Each baseline value was therefore calculated from at least 20 samples for the 1 Hz data sources and 200 samples for the 10 Hz data sources. This background was subtracted from the data values prior to being written to the common format data files. An example common format data file, or PCA file is given in Appendix B.

[1] See Reference 3 for a discussion of the Testbed file structures.

4. 2 VS2 PCA Scaling Factors

The baseline-subtracted data still requires scaling to bring all channels to a normal scale, with a range of 0 to 1. Based on the output characteristics of each sensor channel, a normalization factor for each sensor channel was calculated. For most OFD data channels (OmniGuard UV is the exception), the observed range of values encompassed the entire output range of the channel and the scaling factor was set to the maximum output value of the channel. For the rest of the channels, the scaling factor indicates the maximum observed signal for that channel within the data set. Each data point was divided by this scaling factor prior to being written to the common format data file. The scaling factors are listed in Table 4.1.

4.3 Test Series VS2A and VS2B Differences

As stated above, the VS2 Test Series results have been broken into two groups, VS2A and VS2B, for the analysis. After test number VS2-188, the SBVS Testbed was moved from Compartment 1 to the Passageway. When the sensors were moved, the OmniGuard 860 was damaged. Attempts to fix the unit during testing were unsuccessful. Therefore, there is no OmniGuard 860 data for tests VS2-189 and after. The manufacturer successfully repaired the unit after the test series was completed. The relative normalization factors between the EyeSpy and OmniGuard OFDs were verified using data from the VS2A tests prior to analyzing the VS2B tests using the EyeSpy OFD data.

Table 4.1 – VS2 PCA Scaling Factors

Sensor Channel	Scaling Factor
DAQ	
5900 Å PD	0.1
7665 Å PD	0.1
10500 Å PD	0.1
4.3 µm PbSe	0.005
260 nm PMT	-5
307 nm PMT	-5
OmniGuard OFD	
4.3 µm RefIR	65535
4.3 µm FireIR	65535
UV	255
EyeSpy OFD	
4.3 µm Left IR - DC	255
4.3 µm Right IR - DC	255
Broadband IR – DC	255
4.3 µm Left IR - AC	127
4.3 µm Right IR - AC	127
Broadband IR – AC	127
UV	2550[a]
Thermister	255
Alarm	1

[a] An additional nonlinear filter (10 point) was applied.

5.0 ANALYSIS AND ALGORITHM DEVELOPMENT

5.1 General Algorithm Development Roadmap

Using PCA, a number of factors were extracted from the data set of the thirty-three Candidate Tests. The scores and loadings vectors for each factor were examined in order to identify which sensors were most instrumental in describing useful information. Several examples will be presented in this section. Initial attempts at developing the equivilant of PCs using non-statistical methods [6] provided evidence that there was a significant amount of unique information at wavelengths shorter than the IR, especially with respect to welding detection and general nuisance rejection. Based on these results, reinforced by general observation / inspection of test results, a down selection of sensors was made to five single-element detectors. The obvious redundancy of certain single-element detectors, both in the COTS and in-house detectors was a necessary consequence of a parallel effort in detector technology evaluation. Particularly for the UV and IR detectors, several similar detectors were being evaluated for response characteristics and ease of integration into the final prototype while collecting similar data for algorithm development. Wavelength redundancy amongst the detectors was considered during the algorithm development phase. General event detection criteria were identified, and event classification criteria were developed from the results. The details of the criteria and algorithms will be provided in this section. Using these results, algorithms for post-processing the VS2 Test Series data from the SBVS Testbed were developed, tested, and optimized. These results will be presented. Subsequent to this development, the algorithms were tested for real-time operation during the VS Test Series 3 [9,10]. The real-time performance of the algorithms is briefly discussed in the previous references and will be discussed further in future reports.

5.2 Characteristics of Single-Element Sensors in the Algorithm Development

Before discussing the analysis of the data and the algorithms developed to utilize the data, it is valuable to consider the detector characteristics, such as the spectral response and its relation to source emission, for the individual sensors within the analysis framework. Preliminary analysis of the SBVS Testbed data reinforced by general observation of the test results and coupled with measured flame emission spectra, lead to some initial perceptions. Five detector combinations (IF and detector element combinations) were identified as having the greatest potential for the detection of flaming sources. IR single element detectors have IFs centered at or near the strong 4.3 μm CO_2 emission from flames. Flaming sources also have strong emission in the solar-blind UV region of 185-260 nm. The flame emission spectra also suggested other potential monitoring wavelengths not commonly used for indoor fire detection. Atomic emission of potassium at 766 nm has been reported for remote, satellite fire detection [2] and this concept was adopted for use in the SBVS Testbed. We also observed that fires have appreciable emission at the 589 nm sodium lines, so a detector for this wavelength was included as well. Preliminary analysis of the 589 nm time series data indicated a potential second use for the detector. The amount of ambient 589 nm radiation, from sources such as compartment illumination, impinging on the detector appeared to be sensitive to smoke levels within the space on longer timescales than fire events. Using a technique borrowed from the OFDs, a NIR guard band detector at 1050 nm was added to potentially minimize false alarms. The additional data from the guard band is used to further refine the pattern differences between sources and improved false alarm rejection follows from the use of better patterns.

5.3 Source and Nuisance Principal Components

In this section, the PCA results for the Candidate Tests will be discussed. PCA results include a number of Principal Components (PCs) and the Varimax Principal Component loadings for each PC. File Listing 5.1 provides the Varimax PC loadings for Candidate Test VS2-010, a flaming cardboard box fire within the SBVS Testbed FOV. The leading underscore "_" character for numerically labeled data channels (`_5900A`, for example) is an artifact of the data import process into Oasis montaj. The first column, Channel, lists the data channels included in the PCs. The remaining columns PC1 through PC4, list the individual loading factors for each data channel within each PC. The PC list has been truncated to include only PCs with a calculated eigenvalue of greater than one. A complete listing of the Varimax PC loadings for all the Candidate Tests is given in Appendix C. The complete PCA results are available on the enclosed CD.

File Listing 5.1

```
Jul232003_151943, Test VS2-010, Flaming Boxes with Paper Filling, FOV, Trans

  Channel       PC1     PC2     PC3     PC4

  _5900A       0.003   0.063  -0.929   0.000
  _7665A       0.842   0.264  -0.416   0.000
  _10500A      0.879   0.256  -0.356   0.000
  PbSe         0.000   0.000   0.000   1.000
  UV           0.661   0.165  -0.601   0.000
  Ref_IR       0.927   0.244  -0.247   0.000
  BB_DC        0.960   0.231   0.046   0.000
  Right_DC     0.930   0.178   0.253   0.000
  Left_DC      0.949   0.209   0.144   0.000
  BB_AC        0.262   0.858  -0.057   0.000
  Right_AC     0.247   0.918  -0.079   0.000
  Left_AC      0.209   0.945  -0.084   0.000
  UV_Count     0.633   0.185  -0.304   0.000
```

Four PCs were computed and the Varimax PC loadings are given for each data channel for each PC. A larger loading factor for a data channel indicates that a larger fraction of the PC depends on that data channel. In the case of Candidate Test VS2-010, the majority of the PC loadings come from the 7665 and 10500 Å PDs, the OmniGuard RefIR, all three EyeSpy DC IR, and the EyeSpy UV data channels. An additional PCA result is the eigenvalues associated with each PC. File Listing 5.2 gives the eigenvalues for the 13 PCs calculated along with the cumulative percentage. The cumulative percentage describes with each additional PC how accurately the PC list describes the variation in the original data. In this example, the first PC describes 56.9% of the variation in the data. Adding the second PC describes 70.7% of the variation and so forth. The first four PCs describe almost 90% of the variation in the data.

By evaluating all Candidate Test PCA results, several promising results were extracted. First, tests that had measurable responses from the detectors were typically described by a small number of PCs, even as few as one PC. As a result, the PCA was redone with a limit of 5 PCs per analysis. The summary results are given in Appendix C and the complete results are available on the enclosed CD. Secondly, examination of the first PC (PC1) from all Candidate Tests suggested that a single PC could be used to describe all of the flaming source test results. This single PC was

```
PC1_Flame = (0.489 * 5900A) + (0.980 * 7665A) + (0.969 * 10500A)
            + (0.918 * UV)
```

where `5900A`, `7665A`, `10500A`, and `UV` indicate the scaled signal intensity of the 5900 Å, 7665 Å, 10500 Å, and UV data channels, respectively. This nomenclature of indicating a scaled signal intensity using a different typeface and simplified unit symbols (`A` for Å) is used throughout the remainder of the document.

File Listing 5.2

```
Jul232003_151943, Test VS2-010, Flaming Boxes with Paper Filling, FOV, Trans

Eigenvalues of correlation matrix
---------------------------------
  Factor  Eigenvalue  cum. %
  -------------------------
     1       7.397     56.9
     2       1.791     70.7
     3       1.494     82.2
     4       1.000     89.9
     5       0.536     94.0
     6       0.295     96.3
     7       0.268     98.3
     8       0.101     99.1
     9       0.060     99.6
    10       0.027     99.8
    11       0.016     99.9
    12       0.011    100.0
    13       0.003    100.0
```

Further inspection of the results suggested the following event detection thresholds given in Table 5.1:

Table 5.1 – Initial Flaming PC1 Thresholds

Event Type	PC1 Threshold
Smoke, !FOV[a]	≥ 0.03
Flame, !FOV Smoke, FOV	≥ 0.05
Flame, FOV	≥ 1

[a] !FOV indicates that the source was not within the FOV of the sensor, the opposite of FOV.

Attempts to extract a smoldering PC for the smoldering sources had similar results. The resulting smoldering PC was

```
PC1_Smolder =  (0.577 * 5900A) + (0.948 * 7665A) + (0.9849 * 10500A) +
               (0.056 * RefIR)
```

With such similarity between the PCs for flaming and smoldering, it was clear that a single PC might be able to describe both types of sources simultaniously. This conclusion is further supported by the observations leading to the smoldering source entries in Table 5.1, notionally a flaming source PC. A composite PC, `Sum_N`, was then used for the continued analysis.

```
Sum_N =  (0.500 * 5900A) + (1.000 * 7665A) + (1.000 * 10500A)
         + (1.000 * UV) + (0.100 * RefIR)
```

The quantity `Sum_N` clearly does not involve any EyeSpy data channels. Inspection of the time series data shows that the EyeSpy detectors appear to have a limited dynamic range and sensitivity compared to those of the OmniGuard OFD. This presents a problem for the analysis of the VS2B test data, as the OmniGuard OFD was non-functional during that period of testing.

The data from the EyeSpy UV and IR detectors should contain the same information as the OmniGuard UV and RefIR detector data. Section 5.4 will discuss attempts to recover the same functionality extracted from the OmniGuard OFD using the EyeSpy OFD.

5.4 Event Detection Algorithms

Based on the single-channel data and the `Sum_N` composite, event detection algorithms for four events were developed. These events are: EVENT, SMOKE, FIRE, and FIRE_FOV. The EVENT event was conceived as a generic trigger, indicating that some, currently unclassifiable, event is occurring in the FOV of the sensor. If the `Sum_N` channel data exceeds an empirically determined threshold, an EVENT is declared:

```
If (Sum_N >= 0.05) Then
      EVENT = TRUE
Else
      EVENT = FALSE.
```

The PDSMOKE event makes use of the long-time-scale deviations observed in the `5900A` channel data that were not directly correlated with known flaming events. These deviations were experimentally observed to have either a positive or negative sign depending on the source / detector / illumination geometry. Therefore the absolute value of the baseline corrected, scaled `5900A` channel data is used with an empirically determined threshold to declare a PDSMOKE event:

```
If ABS(5900A) >= 0.05 Then
      PDSMOKE = TRUE
Else
      PDSMOKE = FALSE.
```

The algorithms for FIRE and FIRE_FOV detection compare the measured channel data "spectrum," baseline-corrected, scaled channel values for the five sensors to an empirically determined spectrum for a fully involved flaming fire in the sensor FOV for the FIRE_FOV event, or to a more relaxed spectrum for the FIRE event. The FIRE event criteria are a balance between maximizing detection of non-FOV sources and minimizing false alarms, based on previous test data. The criteria for the FIRE and FIRE_FOV events are:

FIRE:

```
IF (Sum_N >= 0.05) and (5900A >= 0.01) and (7665A >= 0.01) and
      (10500A >= 0.01) Then
      FIRE = TRUE
Else
      FIRE = FALSE.
```

FIRE_FOV:

```
IF (Sum_N >= 0.75) and (5900A >= 0.01) and (7665A >= 0.01) and
      (10500A >= 0.01) Then
      FIRE_FOV = TRUE
Else
      FIRE_FOV = FALSE.
```

Notice that none of these events make explicit use of the `RefIR` or `UV` channel data. They are used in the calculation of `Sum_N`. Also, the only difference in the FIRE and FIRE_FOV events at this stage is the `Sum_N` threshold value. This will not be the case later in the analysis. The data from the Candidate Tests were post-processed using these algorithms and the results are given in Tables 5.2 and 5.3. Probabilities for correct source classification, P_{corr}, of 0.44 to 0.67 were achieved with false alarm probabilities, P_{fa}, of 0.15 or lower. The probability of correct classification is defined as P_{corr} = # of correct classifications / total # of tests and the probability of false alarm is defined as P_{fa} = # of false alarms / total # of tests. The EVENT category is excluded from this assessment of the algorithm results since it was conceived as a trigger event only.

It is evident from the results for the welding tests that they are "bright" with extremely large `Sum_N` values, significant `UV` signal, and little or no `RefIR` signal. A WELDING event detection algorithm was developed based on these characteristics:

WELDING:

```
IF (Sum_N >= 0.05) and (5990A >= 0.01) and (7665A >= 0.01) and
      (10500A >= 0.01) and (RefIR < 0.2) and (UV >= 0.1) Then
      WELDING = TRUE
Else
      WELDING = FALSE.
```

The FIRE_FOV algorithm was also revised to explicitly include IR and UV dependence.

FIRE_FOV:

```
IF (Sum_N >= 0.75) and (5900A >= 0.01) and (7665A >= 0.01) and
      (10500A >= 0.01) and (RefIR >= 0.200) and (UV >= 0.001)
      Then
      FIRE_FOV = TRUE
Else
      FIRE_FOV = FALSE.
```

To improve the classification results and to reduce the number or false alarms, a series of manual optimizations of the algorithms were undertaken. The results gave a final set of threshold values. One adjustment was made to the calculation of `Sum_N` based on analysis of the data. The `5900A` data were originally being included in the calculation of the `Sum_N` value in addition to being used by the Smoke algorithm. It was found that the non-smoke algorithms performed better (fewer false alarms) if the `5900A` data were excluded.

Table 5.2 – Initial Event Detection Results

VS2 Test #	Description	Source?	Trans. ?	FOV ?	EVENT ?	SMOKE?	FIRE ?	FIRE_ FOV?
VS2-064	Smoldering Laundry	Yes		Yes	Yes	Yes	Yes	
VS2-007	Flaming Bedding	Yes	Yes		Yes		Yes	
VS2-010	Flaming Boxes w/ paper fill	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VS2-019	Flaming Boxes w/ paper fill	Yes	Yes		Yes	Yes	Yes	Yes
VS2-165	Smoldering Cable	Yes						
VS2-168	Smoldering Mattress	Yes	Yes		Yes	Yes	Yes	
VS2-177	Smoldering Laundry	Yes	Yes		Yes	Yes	Yes	
VS2-178	Smoldering Trash	Yes	Yes		Yes	Yes	Yes	
VS2-180	Smoldering Wire	Yes						
VS2-181	Smoldering Circuit Boards	Yes						
VS2-096	Smoldering Laundry	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VS2-102	Flaming Wood Crib	Yes	Yes		Yes		Yes	
VS2-114	Smoldering Laundry	Yes	Yes		Yes	Yes	Yes	
VS2-120	Flaming Trash Can	Yes	Yes					
VS2-121	Flaming Trash Can	Yes	Yes	Yes	Yes	Yes		
VS2-126	Smoldering Cable	Yes		Yes	Yes	Yes	Yes	
VS2-131	People Working			?				
VS2-133	Spraying Aerosol			?				
VS2-136	Toast, Burnt					Yes		
VS2-137	Welding				Yes		Yes	
VS2-141	Sunlight							
VS2-145	Person Waving White Shirt			?				
VS2-152	Toast				Yes	Yes		
VS2-154	Welding				Yes	Yes	Yes	Yes
VS2-155	Cutting Steel			Yes	Yes		Yes	
VS2-156	Cutting Steel				Yes		Yes	
VS2-158	Smoldering Monitor	Yes	Yes			Yes		

Table 5.3 – Initial Event Detection Result Summary

EVENT?	PDSMOKE?	FIRE?	FIRE_FOV?
Tests	**Tests**	**Tests**	**Tests**
27	27	27	27
Alarms	**Alarms**	**Alarms**	**Alarms**
17	14	15	4
Correct	**Correct**	**Correct**	**Correct**
17	18	17	12
False Alarms	**False Alarms**	**False Alarms**	**False Alarms**
5	3	4	1
$\mathbf{P_{corr}}$	$\mathbf{P_{corr}}$	$\mathbf{P_{corr}}$	$\mathbf{P_{corr}}$
0.63	0.67	0.63	0.44
$\mathbf{P_{fa}}$	$\mathbf{P_{fa}}$	$\mathbf{P_{fa}}$	$\mathbf{P_{fa}}$
0.19	0.11	0.15	0.04

The final set of criteria and thresholds were:

```
Event:      If (Sum_N >= 0.075) Then
                  EVENT = TRUE
            Else
                  EVENT = FALSE.
Smoke:      If ABS(5900A) >= 0.043 Then
                  PDSMOKE = TRUE
            Else
                  PDSMOKE = FALSE.
Fire:             IF (Sum_N >= 0.075) and (7665A >= 0.015) and
                  (10500A >= 0.015) and (RefIR >= UV) Then
                  FIRE = TRUE
            Else
                  FIRE = FALSE.
Fire_FOV:         IF (Sum_N >= 0.75) and (7665A >= 0.015) and
                  (10500A >= 0.015) and (RefIR >= 0.2) and
                  (UV >= 0.001) Then
                  FIRE_FOV = TRUE
            Else
                  FIRE_FOV = FALSE.
Welding:          IF (Sum_N >= 0.075) and (5990A >= 0.01) and (7665A >=
                  0.01) and (10500A >= 0.01) and (RefIR < 0.2) and (UV
                  >= 0.1) Then
                  WELDING = TRUE
            Else
                  WELDING = FALSE.
```

The final post-processing results of the data from the Candidate Tests using the revised algorithms are given in Tables 5.4 and 5.5. The results are quite promising, as can be readily seen from Table 5.5. Using a fairly simplistic analysis, classification results, P_{corr}, of 0.74 to 0.96 were achieved for the Candidate Tests while maintaining false alarm rates, P_{fa}, of 0.11 and lower. Significant improvement over the initial results is demonstrated (Table 5.3 versus Table 5.5), both

Table 5.4 –Event Detection Results

VS2 Test #	Description	Source?	F/S[a]	Trans ?	FOV ?	EVENT ?	SMOKE ?	FIRE ?	FIRE FOV?	WELD ?
VS2-064	Smoldering Laundry	Yes	S		Yes		Yes			
VS2-007	Flaming Bedding	Yes	F/S	Yes			Yes			
VS2-010	Flaming Boxes w/ paper fill	Yes	F/S	Yes	Yes	Yes	Yes	Yes	Yes	
VS2-019	Flaming Boxes w/ paper fill	Yes	F/S	Yes		Yes	Yes	Yes		
VS2-165	Smoldering Cable	Yes	S							
VS2-168	Smoldering Mattress	Yes	F/S	Yes		Yes	Yes	Yes		
VS2-177	Smoldering Laundry	Yes	F/S	Yes		Yes	Yes	Yes		
VS2-178	Smoldering Trash	Yes	F/S	Yes		Yes	Yes	Yes		
VS2-180	Smoldering Wire	Yes	S				Yes			
VS2-181	Smoldering Circuit Boards	Yes	S							
VS2-096	Smoldering Laundry	Yes	F/S	Yes	Yes	Yes	Yes	Yes	Yes	
VS2-102	Flaming Wood Crib	Yes	F	Yes		Yes	Yes	Yes		Yes
VS2-114	Smoldering Laundry	Yes	F/S	Yes			Yes			
VS2-120	Flaming Trash Can	Yes	F	Yes						
VS2-121	Flaming Trash Can	Yes	F	Yes	Yes	Yes	Yes	Yes		
VS2-126	Smoldering Cable	Yes	S		Yes		Yes			
VS2-131	People Working		N/A		?					
VS2-133	Spraying Aerosol		N/A		?					
VS2-136	Toast, Burnt	Yes	S				Yes			
VS2-137	Welding		N/A			Yes				Yes
VS2-141	Sunlight		N/A							
VS2-145	Person Waving White Shirt		N/A		?					
VS2-152	Toast	Yes	S				Yes			
VS2-154	Welding		N/A			Yes	Yes	Yes		Yes
VS2-155	Cutting Steel		N/A		Yes	Yes		Yes		
VS2-156	Cutting Steel		N/A			Yes		Yes		
VS2-158	Smoldering Monitor	Yes	F/S	Yes			Yes			

[a] F = Flaming Source. S = Smoldering Source

with respect to classification and to false alarm rejection. The EVENT category is excluded from this assessment of the results since it was conceived as a trigger event only and therefore would be prone to false alarms. No persistence criterion was applied to any of these results. This means that if the criteria for a particular event are met at any point in time, an event alarm condition is declared. The addition of persistence or time constants to the algorithms are discussed later in this document and will be shown to improve the algorithm classification results, particularly in terms of false alarm reduction. The use of persistence suppresses alarms from transient signals that are not source related such as a bright flash of light and heat from a cigarette lighter used to start a source or an opening door.

Table 5.5 –Event Detection Result Summary

EVENT?	PDSMOKE?	FIRE?	FIRE_FOV?	WELDING?
Tests	**Tests**	**Tests**	**Tests**	**Tests**
27	27	27	27	27
Alarms	**Alarms**	**Alarms**	**Alarms**	**Alarms**
12	17	11	2	3
Correct	**Correct**	**Correct**	**Correct**	**Correct**
12	23	20	26	26
False Alarm	**False Alarm**	**False Alarm**	**False Alarm**	**False Alarm**
4	1	3	0	1
P_{corr}	P_{corr}	P_{corr}	P_{corr}	P_{corr}
0.44	0.85	0.74	0.96	0.96
P_{fa}	P_{fa}	P_{fa}	P_{fa}	P_{fa}
0.15	0.04	0.11	0.00	0.04

5.5 Recovery of VS2B Data

Since they nominally detect at the same wavelengths, the IR and UV detectors in the EyeSpy and OmniGuard OFDs should have similar performance characteristics. The UV detectors are both gas discharge tube detectors that are sensitive to photons of light with wavelengths shorter than 280 nm. Both 4.3 µm centered IR detectors are uncooled thermopiles with a narrowband IF installed. Due to a combination of the construction of the specific sensors and the dynamic range of the output electronics in each OFD, the OmniGuard OFD appears to offer superior sensitivity and dynamic range. This can be seen in Table 5.6, which contains the scaled, background-subtracted data for 15 seconds of Test VS2-010 starting several seconds prior to the detection of a FIRE event.

In addition to the sensitivity and dynamic range issues between the EyeSpy and the OmniGuard OFDs, there is the question of which IR detector to use? The EyeSpy OFD has three IR detectors, two identical 4.3 µm detectors that are mounted for directional tracking of an IR source. A broadband IR detector was also included. Additionally, the AC- and DC-coupled outputs of the three IR detectors are available in the output. Based on analysis conducted previously [6], several potentially useful combinations of the outputs from the three IR detectors have been identified. The combinations are listed in Table 5.7.

Combination 1 was found to most closely match the OmniGuard `RefIR` detector output in the time series data. A scaling factor of 40 (ES `Combination #1` * 40 ≈ OG `RefIR`) was required to match the amplitudes of the EyeSpy combination and the OmniGuard `RefIR` channels.

Using the EyeSpy `Combination #1`, the Candidate Test data were reprocessed using the EyeSpy data instead of the OmniGuard data. Results strikingly similar to those obtained for the OmniGuard-based results were obtained and are given in Tables 5.8 and 5.9. The EVENT category is again excluded in assessing these results as it was conceived as a trigger event only and therefore would be prone to false alarms. No persistence criterion was applied to any of these results.

Table 5.6 – OmniGuard and EyeSpy Scaled Output comparison

Time (sec)	OG UV[a]	OG IR	ES BB_DC	ES R_DC	ES L_DC	ES BB_AC	ES R_AC	ES L_AC	ES UV
1	0.0039	0.0157	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
2	0.0078	0.0168	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
3	0.0039	0.0178	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
4	0.0078	0.0181	0.0000	0.0000	0.0039	0.0000	-0.0079	0.0000	0.0000
5	0.0314	0.0195	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
6	0.0157	0.0195	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
7	0.0078	0.0195	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
8	0.0157	0.0195	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
9	0.0118	0.0253	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
10	0.0157	0.0279	0.0000	0.0000	0.0039	0.0000	0.0000	0.0079	0.0000
11	0.0078	0.0273	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
12	0.0235	0.0273	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
13	0.0196	0.0273	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
14	0.0078	0.0282	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000
15	0.0118	0.0310	0.0000	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000

[a] ES = EyeSpy OFD. OG = OmniGuard OFD. L = Left 4.3 µm Detector. R = Right 4.3 mm Detector. BB = Broadband IR detector. DC = DC Coupled Output, AC = AC Coupled Output. UV = UltraViolet detector. IR = mid-IR detector.

Table 5.7 – EyeSpy OFD Combination Outputs

Combination #	Definition[a]
1	LPlusR_DC=(Left_DC+Right_DC)/2
2	LPlusR_AC=(Left_AC+Right_AC)/2
3	LROverB_DC=(Left_DC+Right_DC)/(2*BB_DC)
4	LROverB_AC=(Left_AC+Right_AC)/(2*BB_AC)

[a] ES = EyeSpy OFD. OG = OmniGuard OFD. L = Left 4.3 µm Detector. R = Right 4.3 mm Detector. BB = Broadband IR detector. DC = DC Coupled Output, AC = AC Coupled Output. UV = UltraViolet detector. IR = mid-IR detector.

Table 5.8 – EyeSpy-Based Event Detection Results

VS2 Test #	Description	Source?	F/S[a]	Trans. ?	FOV ?	EVENT ?	SMOKE ?	FIRE ?	FIRE FOV?	WELD ?
VS2-064	Smoldering Laundry	Yes	S		Yes		Yes			
VS2-007	Flaming Bedding	Yes	F/S	Yes						
VS2-010	Flaming Boxes w/ paper fill	Yes	F/S	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VS2-019	Flaming Boxes w/ paper fill	Yes	F/S	Yes		Yes	Yes	Yes		
VS2-165	Smoldering Cable	Yes	S							
VS2-168	Smoldering Mattress	Yes	F/S	Yes		Yes	Yes	Yes		
VS2-177	Smoldering Laundry	Yes	F/S	Yes			Yes			
VS2-178	Smoldering Trash	Yes	F/S	Yes			Yes			
VS2-180	Smoldering Wire	Yes	S							
VS2-181	Smoldering Circuit Boards	Yes	S							
VS2-096	Smoldering Laundry	Yes	F/S	Yes	Yes	Yes	Yes	Yes	Yes	Yes
VS2-102	Flaming Wood Crib	Yes	F	Yes		Yes	Yes	Yes		Yes
VS2-114	Smoldering Laundry	Yes	F/S	Yes			Yes			
VS2-120	Flaming Trash Can	Yes	F	Yes						
VS2-121	Flaming Trash Can	Yes	F	Yes	Yes		Yes			
VS2-126	Smoldering Cable	Yes	S		Yes		Yes			
VS2-131	People Working		N/A		?					
VS2-133	Spraying Aerosol		N/A		?					
VS2-136	Toast, Burnt	Yes	S				Yes			
VS2-137	Welding		N/A			Yes				Yes
VS2-141	Sunlight		N/A							
VS2-145	Person Waving White Shirt		N/A		?					
VS2-152	Toast	Yes	S				Yes			
VS2-154	Welding		N/A			Yes	Yes			Yes
VS2-155	Cutting Steel		N/A		Yes					
VS2-156	Cutting Steel		N/A							
VS2-158	Smoldering Monitor	Yes	F/S	Yes			Yes			

[a] F = Flaming Source. S = Smoldering Source

Table 5.9 – EyeSpy-Based Event Detection Result Summary

EVENT?	PDSMOKE?	FIRE?	FIRE_FOV?	WELDING?
Alarms	**Alarms**	**Alarms**	**Alarms**	**Alarms**
7	15	5	2	5
Tests	**Tests**	**Tests**	**Tests**	**Tests**
27	27	27	27	27
Correct Alarms	**Correct Alarms**	**Correct Alarms**	**Correct Alarms**	**Correct Alarms**
11	21	20	26	24
False Alarms	**False Alarms**	**False Alarms**	**False Alarms**	**False Alarms**
2	1	0	0	3
P_{corr}	P_{corr}	P_{corr}	P_{corr}	P_{corr}
0.41	0.78	0.74	0.96	0.89
P_{fa}	P_{fa}	P_{fa}	P_{fa}	P_{fa}
0.07	0.04	0.00	0.00	0.11

6.0 EVENT ALGORITHM OPTIMIZATION

6.1 Optimization Methodology

Manual optimization of the algorithm design and criteria demonstrated significant classification ability with reasonable false alarm rejection. A systematic optimization approach was undertaken to more rigorously test and optimize the nascent algorithms. Two new data sets were extracted from the VS2 Test Series data for the optimization step. A collection of 62 tests was selected for testing smoke-related algorithms. The collection was composed of 46 non-transitioning, smoldering source tests, 6 flaming source tests, and 10 nuisance sources. A second, flaming source collection was generated from 100 VS2 tests, composed of flaming test sources; smoldering; not-transitioning test sources; and nuisance sources. Complete lists of each collection are given in Appendix D. Many of the tests included in the candidate tests evaluated in algorithm development are included in both of the new collections with the exception of any VS2B tests (tests VS2-188 and higher).

A single parameter was optimized in each run. For threshold parameters, a range of values, typically –30% to +30% of the original value was used to process the data from the appropriate collection. All other threshold and rules remained at the original values/conditions. For One-Rule-Out studies, a single algorithm criterion was removed from the algorithm. All other thresholds and criteria remained at the original values/conditions. As one caveat, the definition of the Sum_N PC was not varied as the removal of individual criteria was evaluated. This is another potential avenue for further analysis. The results were then plotted as receiver operating characteristic (ROC) style curves [16] and as a function of average response time. In both cases, the overall statistics and average times for the entire collection were the values optimized. All algorithm parameters were optimized individually, and then permutations of removing one criterion at a time were conducted for each algorithm with more than one criterion. After optimization, the entire VS2 data set was processed using the optimized parameters. These results are discussed in Section 7. Further optimization by repeating the process would further refine the algorithms, if required in the future.

As part of the optimization methodology, the concept of persistence was incorporated into the post-processing. The idea is to improve rejection of transient events such as a bright flash of light from a lighter or from test personnel moving through the space. The processing flow is modified so that an algorithm must indicate an alarm condition for a set period of time before the alarm is indicated and logged. The persistence value is a parameter for optimization as well. The general logic used is indicated below:

```
Persistence:
    IF EVENT_TYPE = TRUE
            EVENT_TYPE.IndexCount = EVENT_TYPE.IndexCount + 1
            IF EVENT_TYPE.IndexCount > Persistence { + Duration)
                EVENT_TYPE.IndexCount = Persistence { +
                    Duration)
    ELSE
            EVENT_TYPE.IndexCount = EVENT_TYPE.IndexCount – 1
            IF EVENT_TYPE.IndexCount < 0
                EVENT_TYPE.IndexCount = 0
    IF EVENT_TYPE.IndexCount >= Persistence
            EVENT_TYPE.ALARM = TRUE
    ELSE
            EVENT_TYPE.ALARM = FALSE.
```

This persistence algorithm works well for detecting the first alarm within an event category while post-processing a test. For a real-time system, one might wish to set a minimum time that an event alarm would remain active for operator evaluation. This could be implemented by adding the optional `Duration` term shown above. Prior to optimizing any parameter for the SBVS events, a persistence study was conducted. For an example, the FIRE event algorithm was examined with the default parameters.

The probability of detection (P_d = # of sources detected / total # of sources), probability of correct classification (P_{corr} = # of correct classifications / total # of tests), probability of false alarm (P_{fa} = # of false alarms / total # of tests), and average response time (referenced to ignition time, in seconds) were evaluated. The results are shown in Figure 6.1. Figure 6.1 is composed of two graphs. The upper graph plots P_d and P_{corr} versus P_{fa} as a function of persistence value. The vertical scale for P_d is given on the left side of the graph and on the right side for P_{corr}. The lower graph plots the average response time for each persistence value evaluated. The apparent disparity in number of data points between the upper and lower graphs is due to the fact that some ranges of persistence value yield the same P_d / P_{corr} /P_{fa} results. Evaluation of nine persistence values yielded six unique P_d / P_{corr} /P_{fa} values. The remaining Figures in this section will be of a similar format. The results indicate an initial decrease in P_d and P_{corr} with the minimal persistence of 2 seconds. For any additional persistence increase, the P_d falls while the P_{corr} rises, as one might expect. Eventually, the persistence threshold is large enough that a significant number of detections are being missed, and P_d and P_{corr} drop. The average response time increases initially, drops, and then begins to climb again. A persistence of 5 seconds was chosen as the best tradeoff

between detections and false alarms with reasonable response times. The `Duration` term was set to zero for this analysis.

6.2 PDSMOKE Algorithm Optimization

The PDSMOKE event makes use of the long time-scale deviations observed in the `5900A` channel data that were not directly correlated with known flaming events. These deviations were experimentally observed to have either a positive or negative sign depending on the source / detector / illumination geometry. Therefore the absolute value of the baseline corrected, scaled `5900A` channel data is used with an empirically determined threshold to declare a PDSMOKE event:

```
If ABS(5900A) >= 0.043 Then
      PDSMOKE = TRUE
Else
      PDSMOKE = FALSE.
```

The threshold value for declaring a PDSMOKE event was varied and the results are shown in Figure 6.2.

Based on the above analysis, a ten percent reduction in the threshold increases P_d from 0.56 to 0.69 with no increase in P_{fa} (= 0.016). The results indicate that the two gained event detections do not fit the spectral or temporal profile for a smoldering event and should be counted as "lucky," not true, detections [17]. The PDSMOKE `5900A` threshold value is therefore not changed from its original value, 0.043.

6.3 EVENT Algorithm Optimization

The EVENT event was conceived as a generic trigger, indicating that some, currently unclassifiable event is occurring in the FOV of the sensor. If the `Sum_N` channel data exceeds an empirically determined threshold, an EVENT is declared:

```
If (Sum_N >= 0.075) Then
      EVENT = TRUE
Else
      EVENT = FALSE.
```

The threshold value for declaring an EVENT event was varied and the results are shown in Figure 6.3. An increase in the Sum_N threshold from 0.075 to 0.0825 reduces the P_{fa} from 0.06 to 0.04 for the same P_d, 0.895, and yields a 40 second improvement in average response time. The 0.02 reduction in P_{fa} translates into a 0.02 gain in P_{corr} as well. Based on these results, the EVENT Sum_N threshold was increased to 0.0825.

As a PDSMOKE event is a subset of the SBVS events, reaction of the PDSMOKE algorithm should be considered in the generic EVENT algorithm as well. Therefore, an analysis run was conducted where a possible threshold for inclusion of the `5900A` channel data into the EVENT algorithm. Figure 6.4 gives the results and indicates that the addition of the `5900A` channel data immediately improves the classification statistics, P_d and P_{corr}, from 0.78 to 0.98 and

from 0.78 to 0.96, respectively. The average increase in average response time is 5 seconds, or 200 seconds total rather than 195 seconds. An absolute-valued `5900A` channel threshold of 0.015 was added to the EVENT algorithm:

```
If (Sum_N >= 0.075) or (ABS(5900A >= 0.015) Then
      EVENT = TRUE
Else
EVENT = FALSE.
```

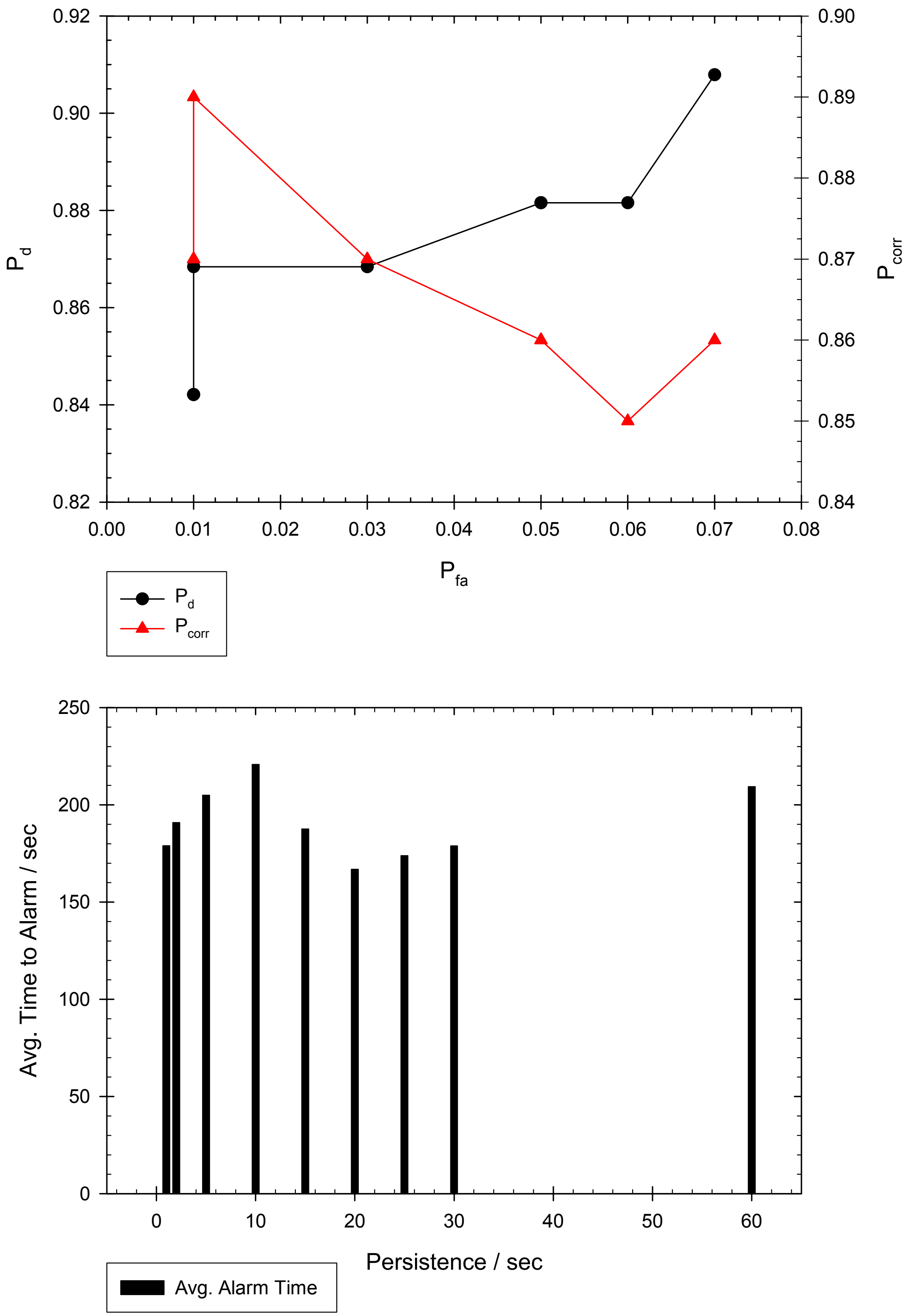
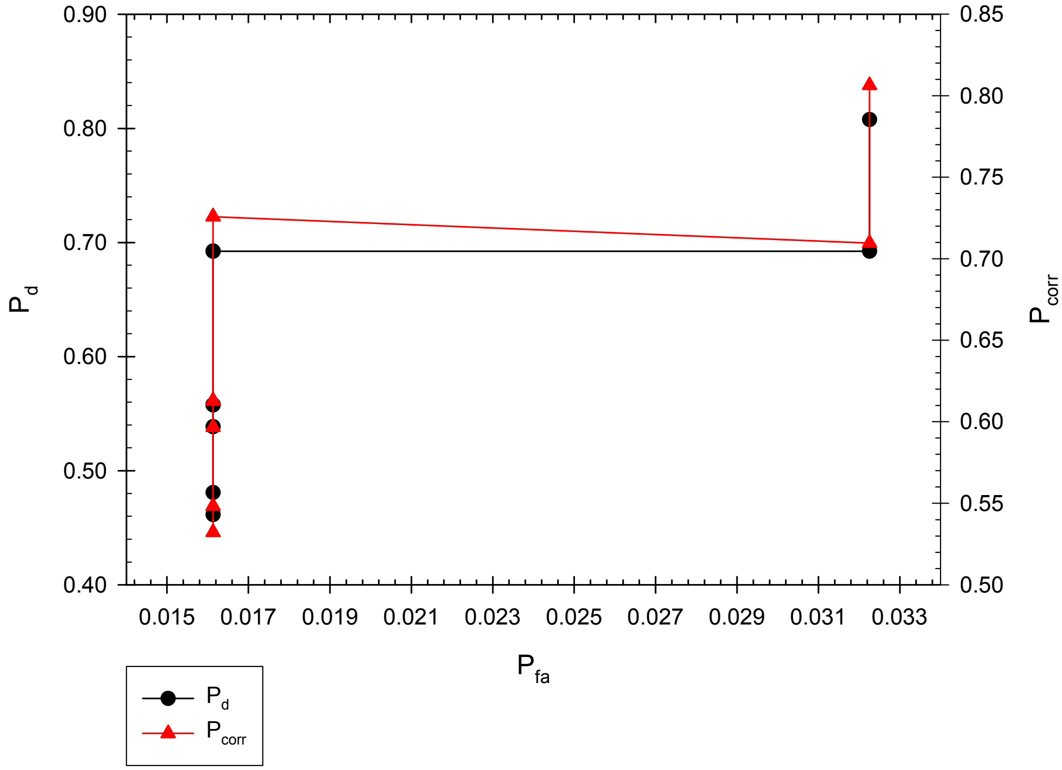


Fig. 6.1 – Persistence Threshold Optimization Results for FIRE event



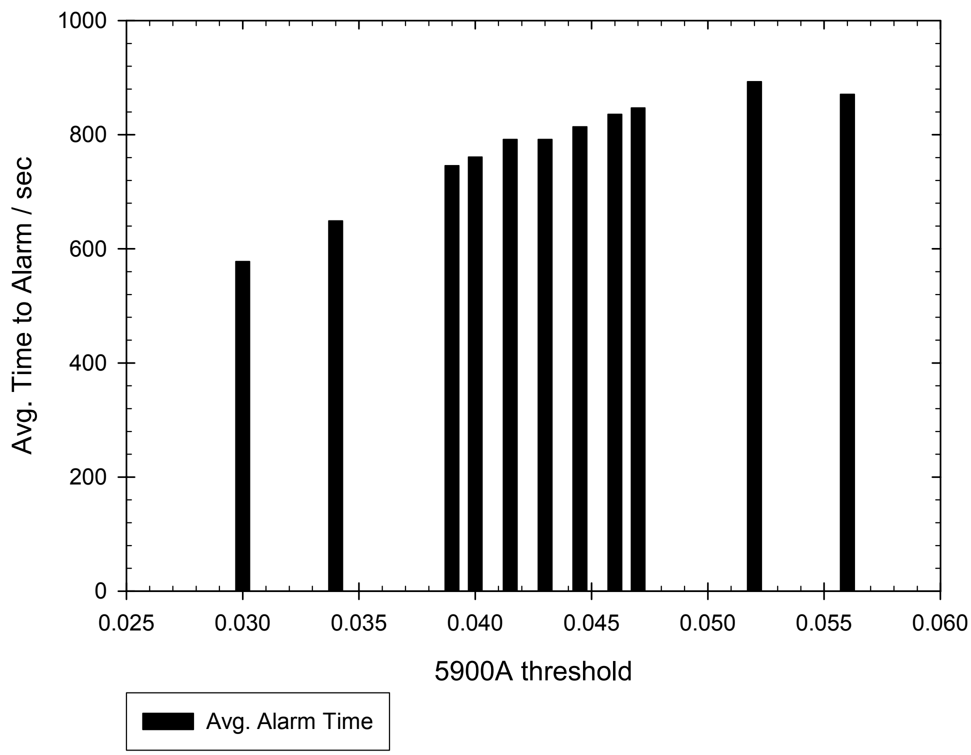


Fig. 6.2 – PDSMOKE 5900 Å Threshold Optimization Results

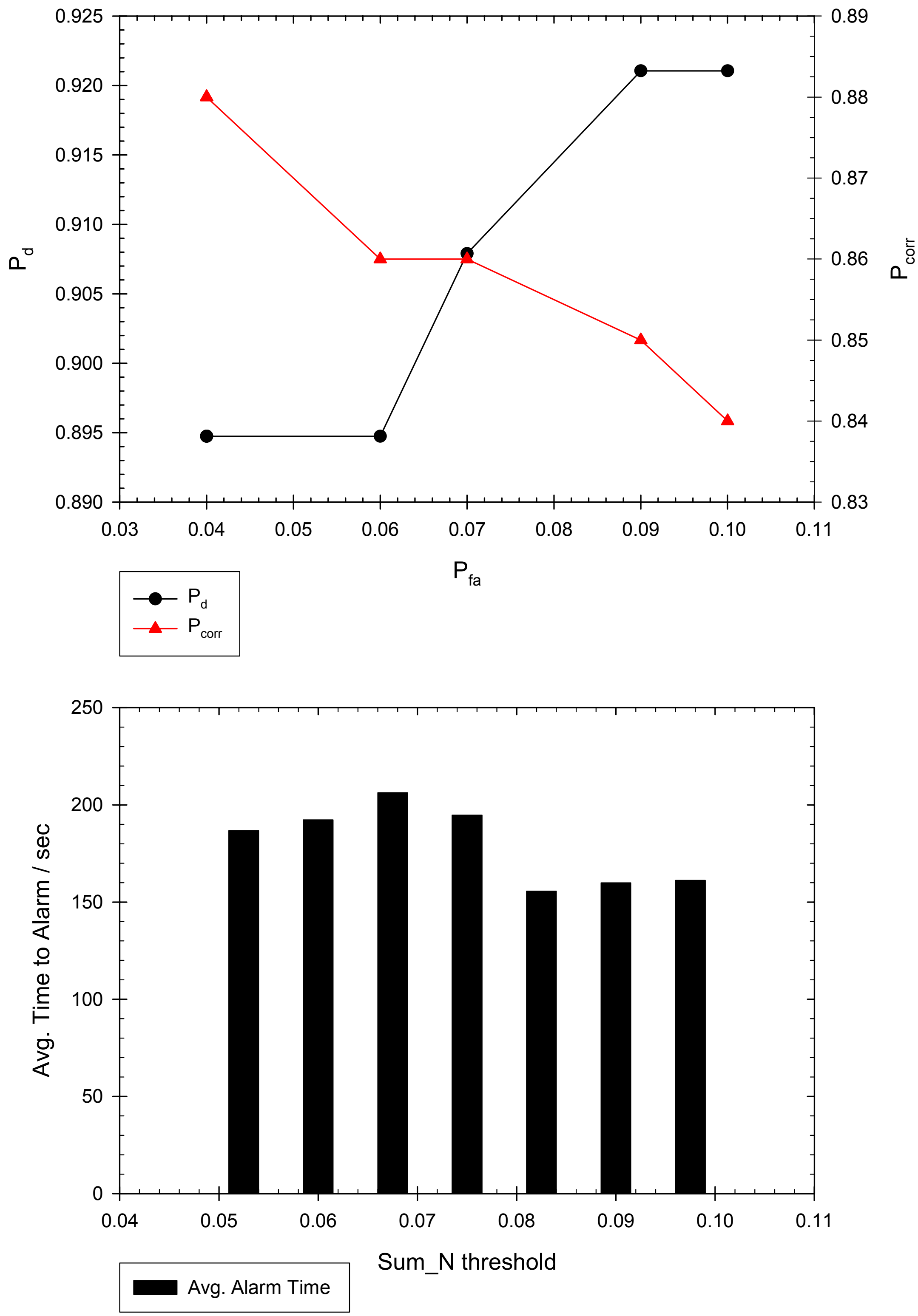


Fig. 6.3 – EVENT Sum_N Threshold Optimization Results

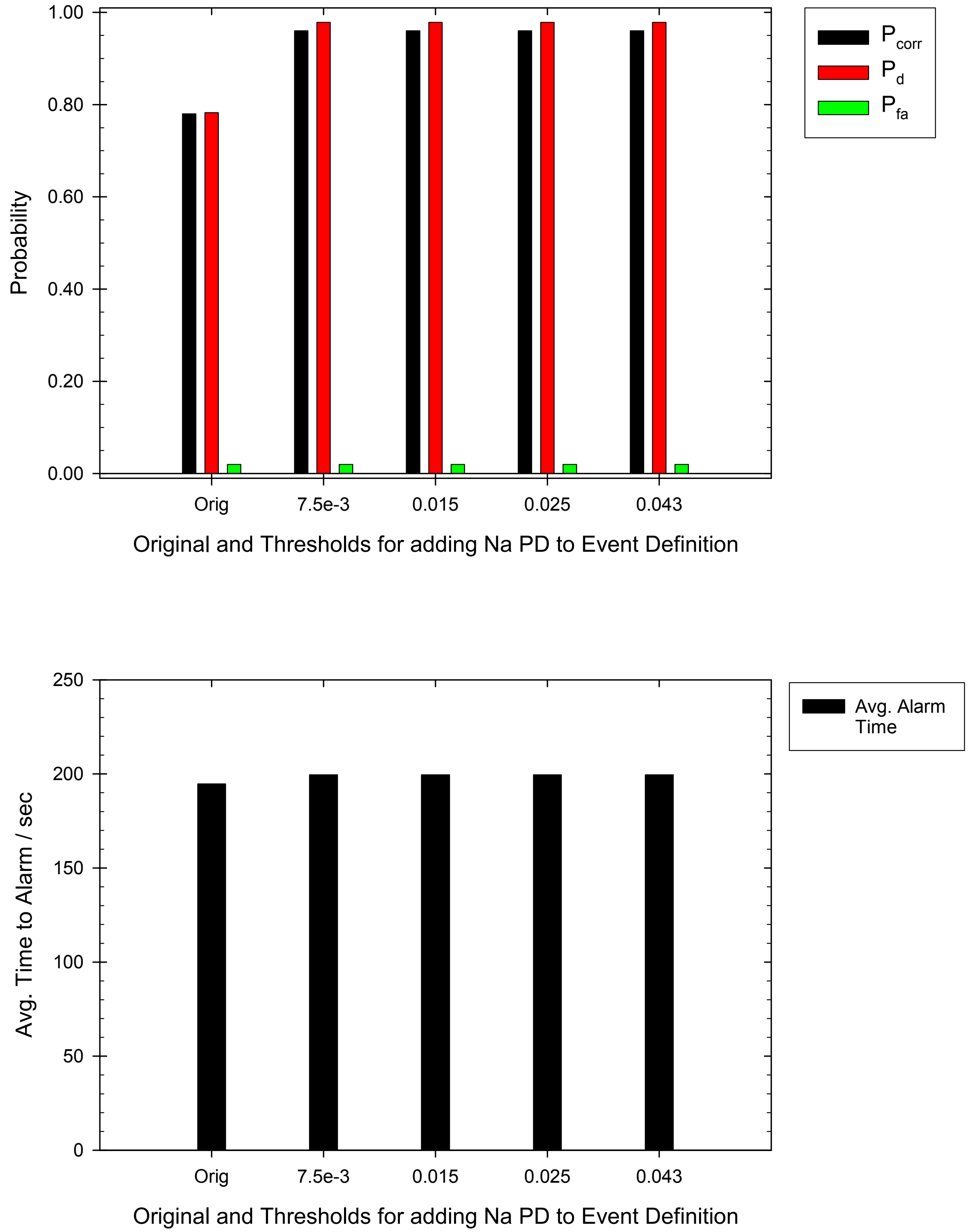


Fig. 6.4 – EVENT 5900 Å Threshold Optimization Results

6.4 FIRE Algorithm Optimization

The FIRE detection algorithm compares the measured channel data "spectrum," baseline-corrected, scaled channel values for the five sensors to an empirically determined spectrum. The FIRE event criteria are a balance between maximizing detection of non-FOV sources and minimization of false alarms, based on previous test data. The initial criteria for the FIRE are:

FIRE:

```
IF (Sum_N >= 0.075) and (7665A >= 0.015) and (10500A >= 0.015)
      and (RefIR >= UV) Then
      FIRE = TRUE
Else
      FIRE = FALSE.
```

The `Sum_N` threshold value for declaring a FIRE event was varied and the results are shown in Figure 6.5. An increase in the `Sum_N` threshold from 0.075 to 0.0825 reduces the P_{fa} from 0.05 to 0.03 for the same P_d, 0.882, and yields a 40 second improvement in average response time. The 0.02 reduction in P_{fa} translates into a 0.02 gain in P_{corr} as well. Based on these results, the FIRE `Sum_N` threshold was increased to 0.0825.

As a crosscheck of the earlier PCA, individual or groups of criteria and/or thresholds involved in the FIRE event algorithm were tested for their impact on the overall algorithm. This was done by systematically removing one criterion or threshold and reprocessing the data set. The results are given in Figure 6.6. The criteria that caused a measurable change in the classification statistics were a) the `Sum_N` and b) the combination of UV and IR criteria. Both criteria changes caused a general sensitivity increase, resulting in faster response times, higher P_d, and higher P_{fa}. For the `Sum_N` criteria, the P_{corr} also decreased. It is somewhat surprising that removal of a criterion or two has such as small effect. This may be due to the fact that each criterion is already fairly strict and therefore work quite well independently. As the cost of increased P_d and decreased alarm time was increased P_{fa}, no additional changes were made to the FIRE algorithm based on this crosscheck.

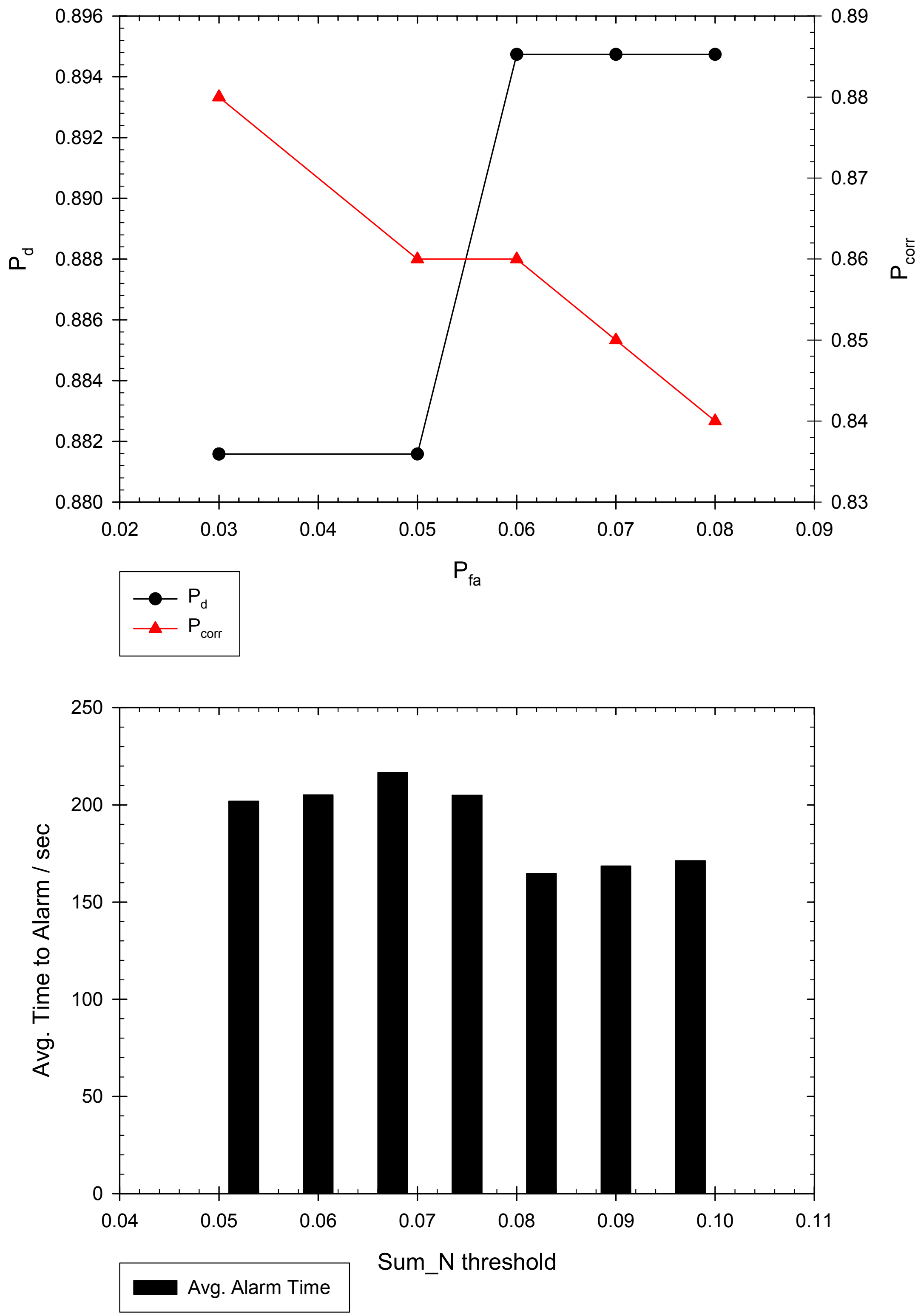


Fig. 6.5 – FIRE Sum_N Threshold Optimization Results

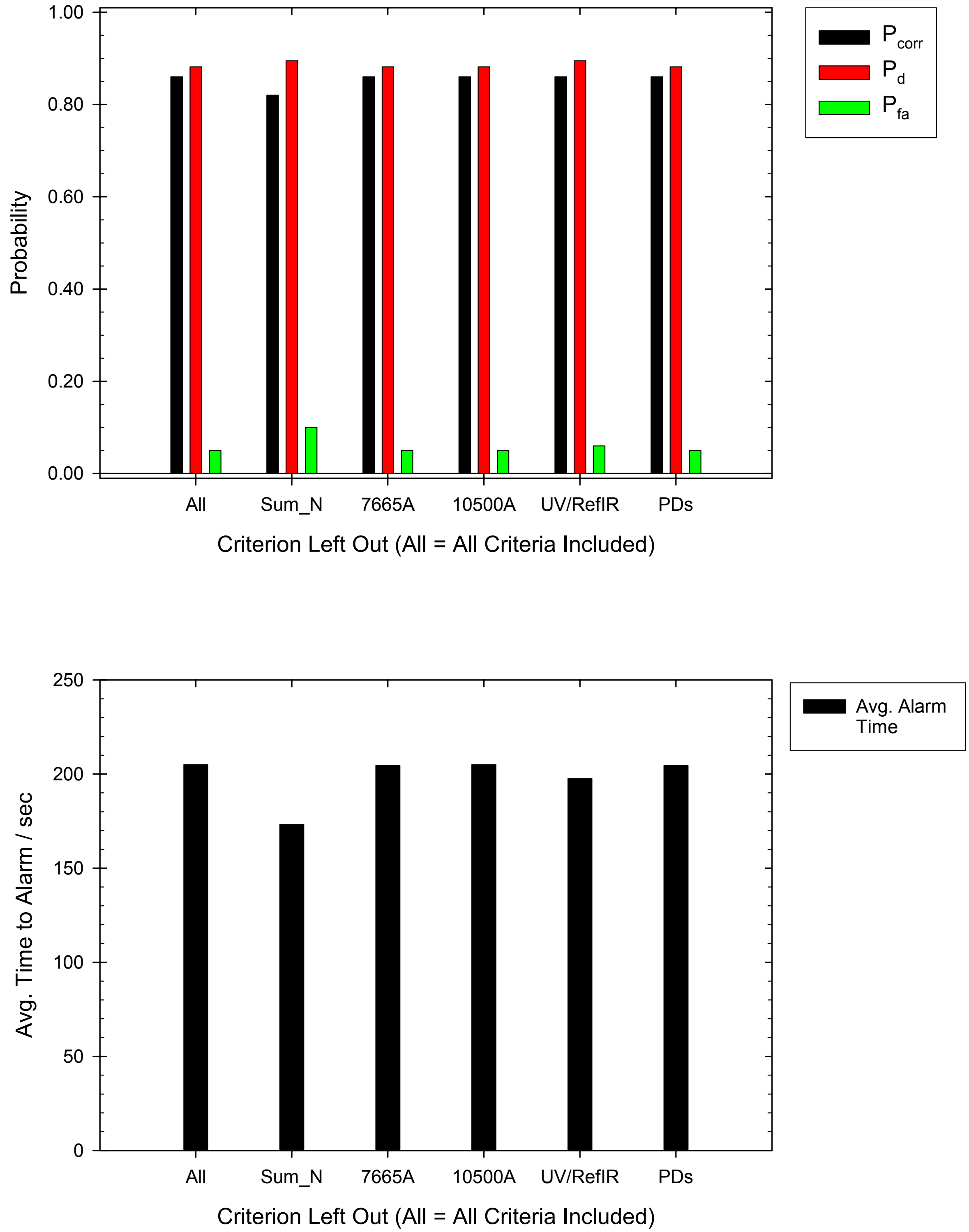


Fig. 6.6 – FIRE One-Rule-Out Optimization Results

6.5 WELDING Algorithm Optimization

An algorithm for the positive detection of one nuisance, arc welding, was developed through the analysis of the VS1 and VS2 Test Series data from the SBVS Testbed. Existing data indicated that nuisances such as arc welding and the operation of an oxyacetylene torch have a distinctive "spectrum" when monitored by the SBVS Testbed. The "spectrum" is significantly shifted from the IR for a flaming event to the visible and UV. The initial criteria for the WELDING nuisance detection is:

```
IF (Sum_N >= 0.075) and (7665A >= 0.015) and (10500A >= 0.01) and
      (RefIR < 0.2) and (UV >= 0.1) Then
            WELDING = TRUE
      Else
            WELDING = FALSE.
```

The `Sum_N` threshold value for declaring a WELDING event was varied and the results are shown in Figure 6.7. The results for a `Sum_N` threshold ranging from 0.0525 to 0.0975 are invariant with a P_{fa} of 0.02, a P_d of 0.974, a P_{corr} of 0.980, and an 80 second average response time. Based on these results, the WELDING `Sum_N` threshold was increased to 0.0825 to correspond with the other event `Sum_N` threshold values to improve performance while maintaining a single `Sum_N` threshold for a majority of the event algorithms.

The `UV` threshold value for declaring a WELDING event was varied and the results are shown in Figure 6.8. For `UV` thresholds ranging from 0.50 down to 0.175, the results are invariant with a P_{fa} of 0.01, a P_d of 1.00, a P_{corr} of 0.99, and a 50 second average response time. For threshold values below 0.175, the P_{fa} begins to rise rapidly. Based on these results, the WELDING `UV` threshold was increased to 0.15. A value slightly below the 0.175 test value was selected based on the curvature of the average response time plot.

The `RefIR` threshold value for declaring a WELDING event was varied and the results are shown in Figure 6.9. The results for the `RefIR` thresholds were invariant for detections over a range from 0.002 to 0.5, with a $P_d = 1.00$. The P_{fa} values ranged from 0.01 to 0.03 over the same range, and correspondingly, the P_{corr} ranged from 0.99 to 0.97. The average response time was three-tiered over the range of thresholds explored. Based on these results, the WELDING `RefIR` threshold was decreased to 0.056. The decreased value offered superior response times, an average of 50 seconds down from a maximum of 109 seconds.

As a crosscheck of the earlier PCA, individual or groups of criteria and/or thresholds involved in the WELDING event algorithm were tested for their impact on the overall algorithm. This was done by systematically removing one criterion or threshold and reprocessing the data set. The results are given in Figure 6.10. The criteria that caused a measurable change in the classification statistics were a) the UV and b) the IR criteria. Both criteria changes resulted in slower response times, higher P_{fa} and lower P_{corr}, especially for the UV criterion. As there was no clear improvement with the removal of any single criterion with respect to any of the metrics evaluated, and quite the contrary for two of the criteria, no criterion was recommended for removal from the WELDING algorithm based on these crosscheck results.

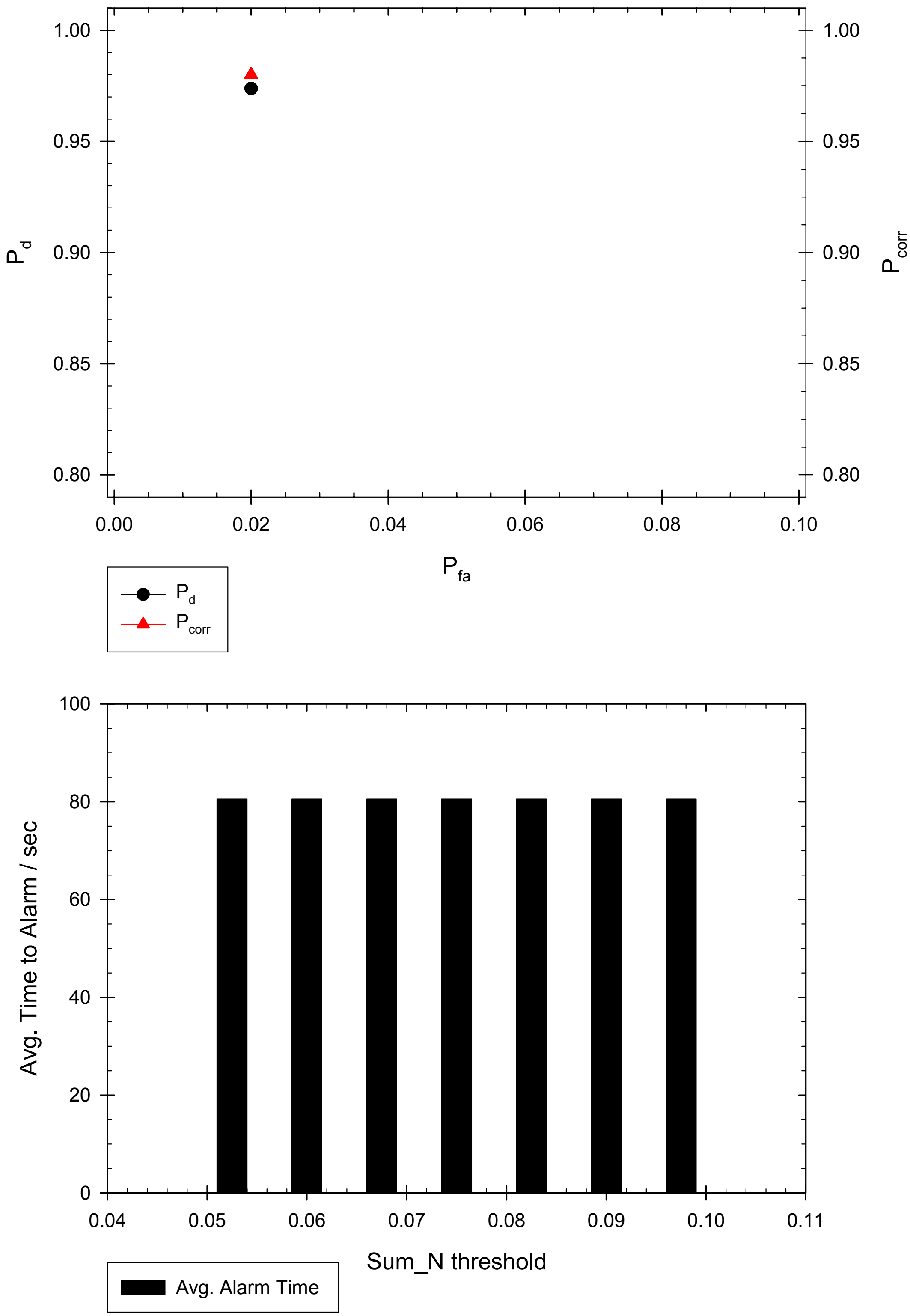
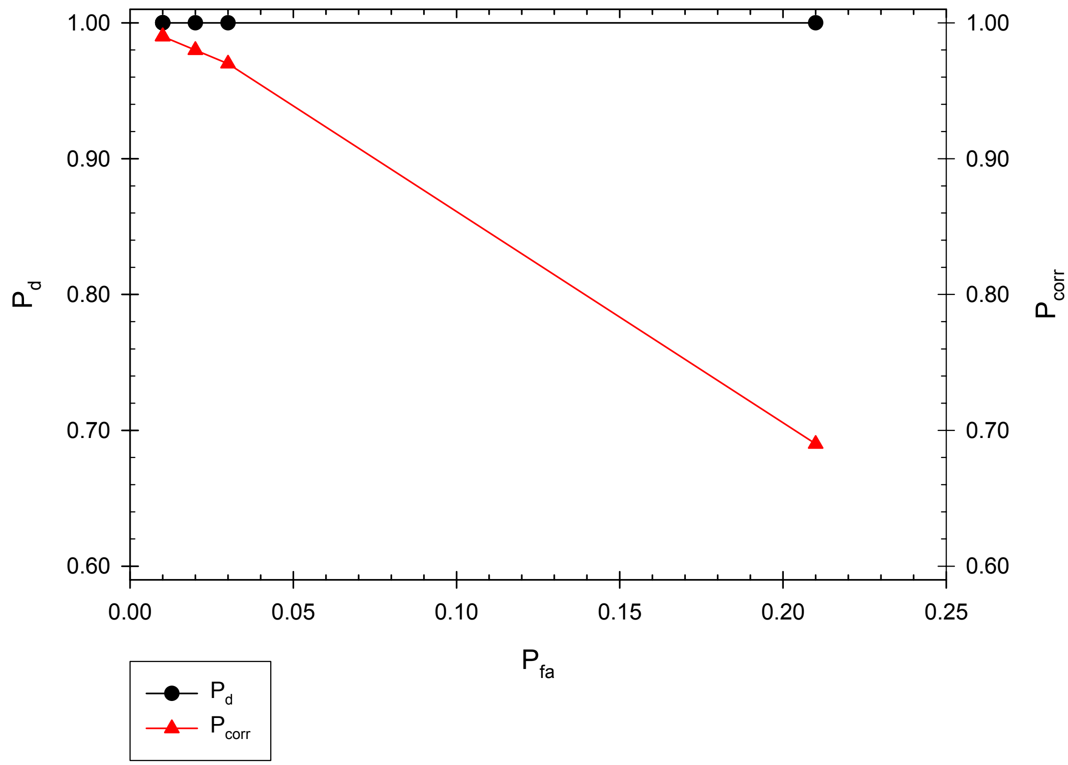


Fig. 6.7 – WELDING Sum_N Threshold Optimization Results



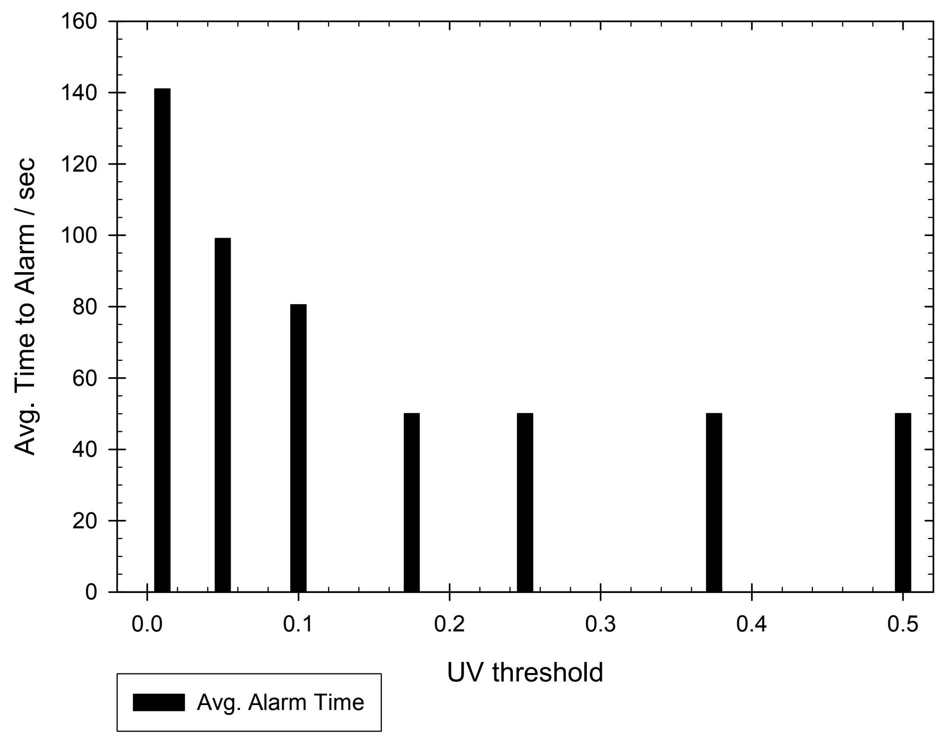


Fig. 6.8 – WELDING UV Threshold Optimization Results

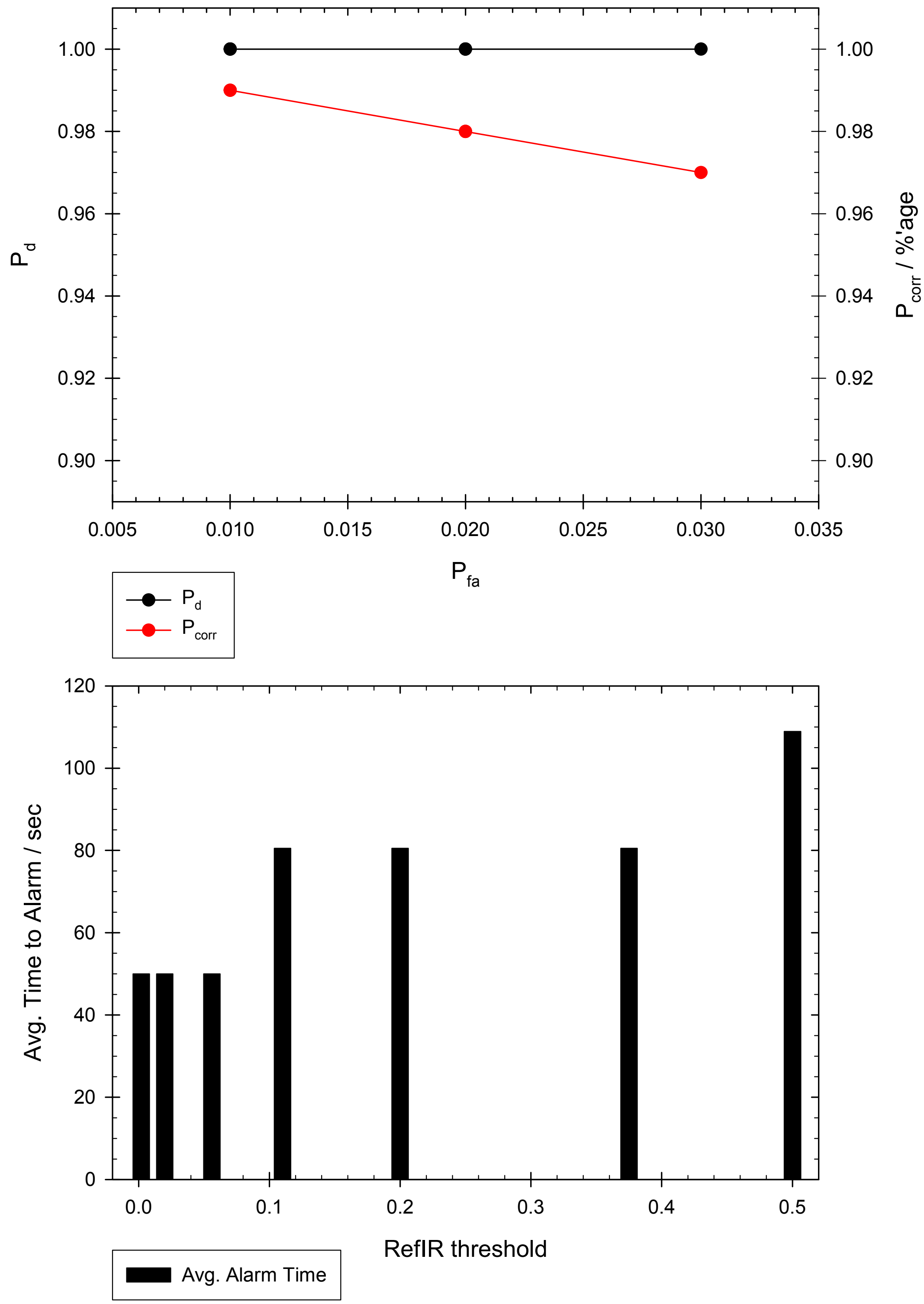


Fig. 6.9 – WELDING RefIR Threshold Optimization Results

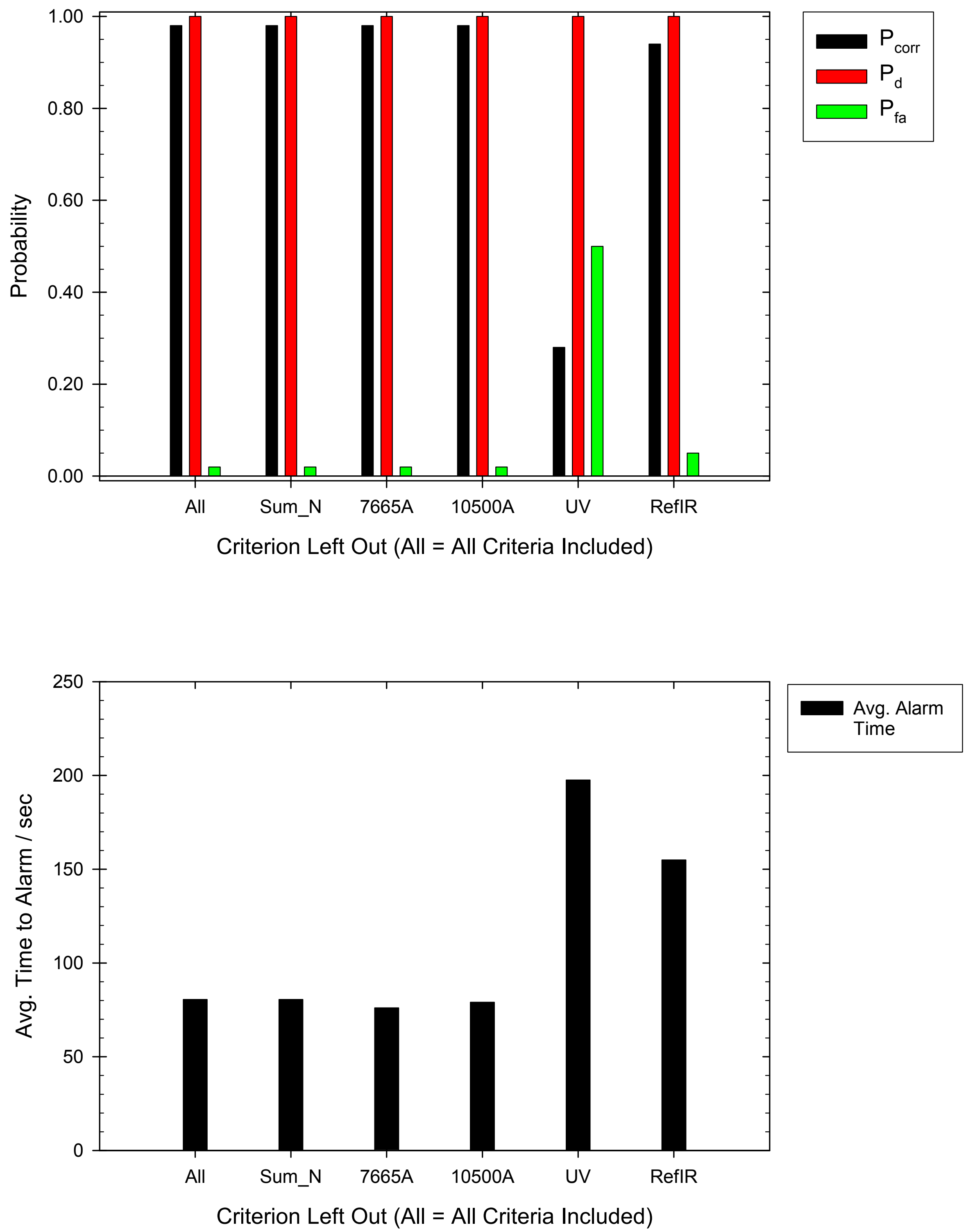


Fig. 6.10 – WELDING One-Rule-Out Optimization Results

6.6 FIRE_FOV Algorithm Optimization

The detection algorithm for FIRE_FOV compares the measured channel data "spectrum," baseline-corrected, scaled channel values for the five sensors to an empirically determined spectrum for a fully involved flaming fire in the sensor FOV. The initial criteria for the FIRE_FOV event are:

FIRE_FOV:
```
IF (Sum_N >= 0.75) and (7665A >= 0.015) and (10500A >= 0.015) and
      (RefIR >= 0.2) and (UV >= 0.001) Then
            FIRE_FOV = TRUE
      Else
            FIRE_FOV = FALSE.
```

The `Sum_N` threshold value for declaring a FIRE_FOV event was varied and the results are shown in Figure 6.11. The results for a `Sum_N` threshold ranging from 0.0825 to 0.975 are invariant with respect to P_{fa}, 0.00. The P_d ranged from 0.395 to 0.342 while the P_{corr} ranged from 0.54 to 0.52. These statistics are calculated for all flaming sources, not just the FOV sources, so absolute values of the statistics are lower than one might expect. The average response time showed a weak increase with increase `Sum_N` threshold with an inflection point between 0.600 and 0.525. Based on these results, the FIRE_FOV `Sum_N` threshold was decreased to 0.600 as a compromise between reaction time and selectivity.

The `RefIR` data channel threshold was also optimized and the results are shown in Figure 6.12. There was no dependence on the FIRE_FOV `RefIR` threshold for a range of 0.10 up to 0.26. At a threshold value of 0.26, the P_d and P_{corr} dropped from 0.37 and 0.52 to 0.36 and 0.51, respectively. The average alarm time showed a very weak trend from 236 to 239 seconds over the range and the P_{fa} was 0.00. As there was no significant dependence on the `RefIR` threshold value, it was left unchanged at the original, coarse optimization value of 0.2.

As a crosscheck of the earlier PCA, individual or groups of criteria and/or thresholds involved in the FIRE_FOV event algorithm were tested for their impact on the overall algorithm. This was done by systematically removing one criterion or threshold and reprocessing the data set. The results are given in Figure 6.13. The only criterion that caused a measurable change in the classification statistics was the `RefIR` criterion. Removal of the `RefIR` criterion increased the P_{fa} from 0.00 to 0.02. It is somewhat surprising that removal of a criterion or two has such as small effect. This may be due to the fact that each criterion is already fairly strict and therefore work quite well independently. As each criterion involved in the FIRE_FOV algorithm is an integral piece in building the data "spectrum" used in classification process, no criterion was removed from the algorithm at this time. Furthermore, there are plans to reduce the number of sensors in the future, but not until after evaluating which sensors work best in combination with other sensor data available within the Volume Sensor Prototype.

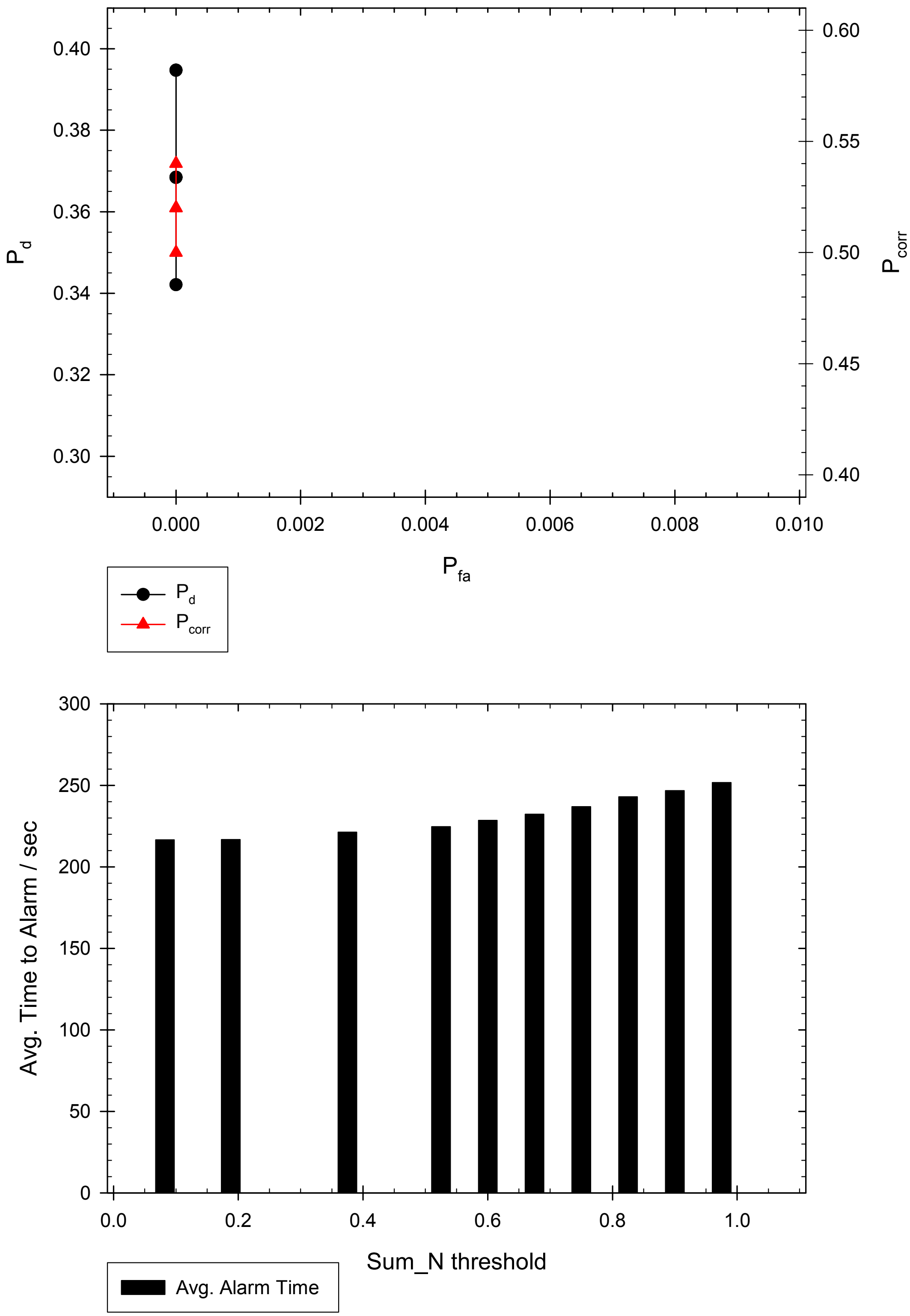


Fig. 6.11 – Fire_FOV Sum_N Threshold Optimization Results

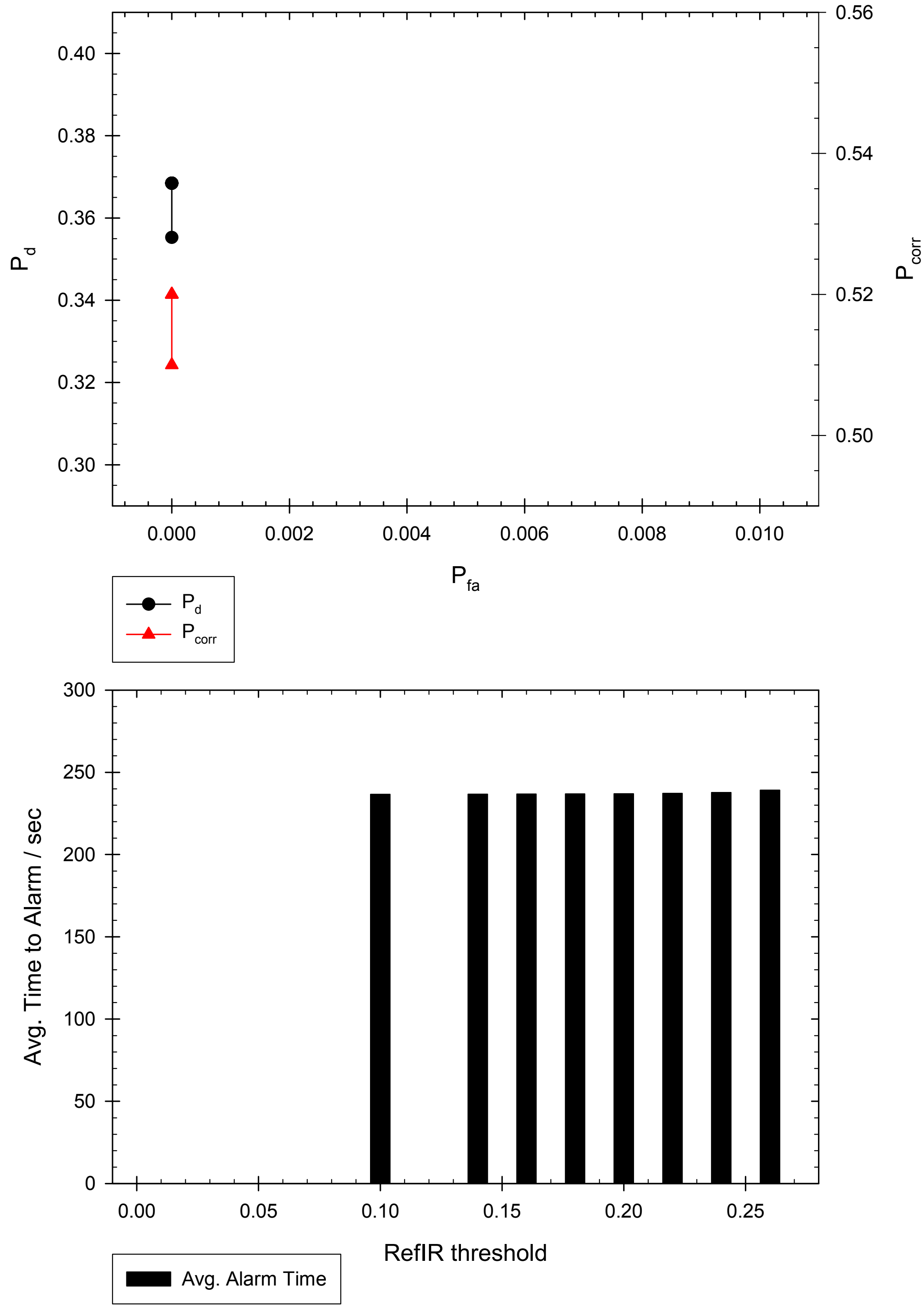


Fig. 6.12 – Fire_FOV IR Threshold Optimization Results

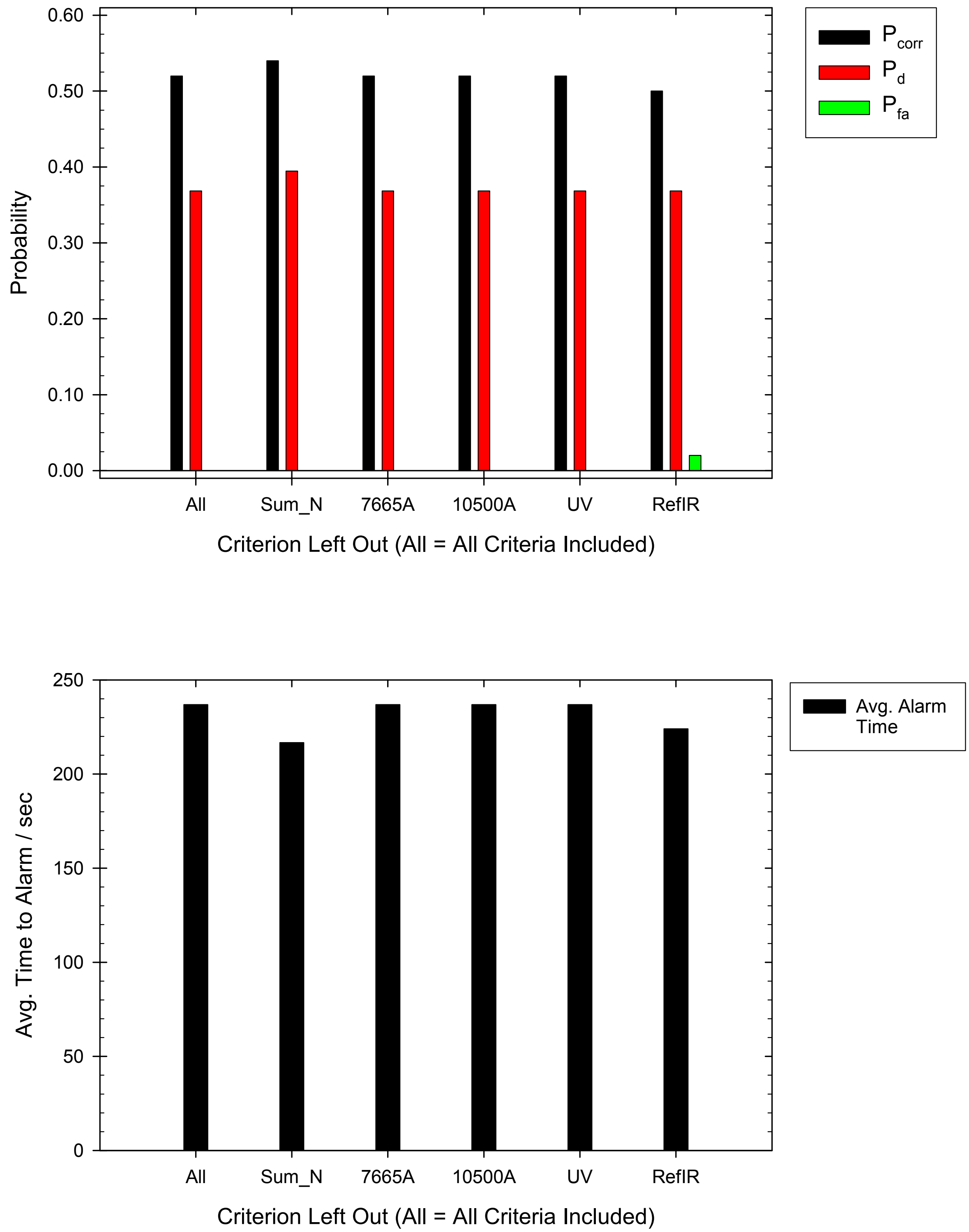


Fig. 6.13 – Fire_FOV One-Rule-Out Optimization Results

6.7 Final, Optimized Algorithm Configuration

Based on the optimization results, a finalized set of event criteria and thresholds were determined. The final set of criteria and thresholds are:

```
Event:      If (Sum_N >= 0.0825) or (Abs(5900A) >= 0.015) Then
                  EVENT = TRUE
            Else
                  EVENT = FALSE.

Smoke:      If Abs(5900A) >= 0.043 Then
                  PDSMOKE = TRUE
            Else
                  PDSMOKE = FALSE.

Fire:       IF (Sum_N >= 0.0825) and (7665A >= 0.015) and
            (10500A >= 0.015) and (RefIR >= UV) Then
                  FIRE = TRUE
            Else
                  FIRE = FALSE.

Fire_FOV:   IF (Sum_N >= 0.6) and (7665A >= 0.015) and
            (10500A >= 0.015) and (RefIR >= 0.2) and (UV >= 0.001) Then
                  FIRE_FOV = TRUE
            Else
                  FIRE_FOV = FALSE.

Welding:    IF (Sum_N >= 0.0825) and (5990A >= 0.01) and
            (7665A >= 0.01) and (10500A >= 0.01) and (RefIR < 0.2) and
            (UV >= 0.1) Then
                  WELDING = TRUE
            Else
                  WELDING = FALSE.

Persistence:

      IF EVENT_TYPE = TRUE

                  EVENT_TYPE.IndexCount = EVENT_TYPE.IndexCount + 1

                  IF EVENT_TYPE.IndexCount > 5

                        EVENT_TYPE.IndexCount = 5

      ELSE

                  EVENT_TYPE.IndexCount = EVENT_TYPE.IndexCount – 1

                  IF EVENT_TYPE.IndexCount < 0

                        EVENT_TYPE.IndexCount = 0

      IF EVENT_TYPE.IndexCount >= Persistence

                  EVENT_TYPE.ALARM = TRUE

      ELSE

                  EVENT_TYPE.ALARM = FALSE.
```

Using the optimized algorithm parameters, the entire VS2 data set was post-processed and the results are presented in the next section of this document.

6.8 Evolution of the Single-Element Sensor Selection for Algorithms

After the development of several sucessful algorithms for DC event detection, it is worthwhile to review the physical context for the individual sensors within the final algorithm framework. Down selection to five unique detector combinations (IF and detector element pairs) was made and five successful algorithms were developed for the detection of flaming, smoldering, and welding nuisance sources. The quantity `Sum_N`, a linear combination of four of the five detectors (`7665A`, `10500A`, `RefIR`, and `UV`), was found to be a powerful predictor for the occurance of an event within the SBVS Testbed's FOV. The strength of the 589 nm sodium line detector was found to be in the detection of smoke via variation in the amount of ambient illumination reflected to the detector, as demonstrated with the PDSMOKE algorithm. While the 589 nm detector does measure flame emission in the neighborhood of 589 nm, the `5900A` data channel was not significant to the developed FIRE and FIRE_FOV algorithms and they do not include it. The WELDING algorithm also does not make use of the `5900A` data channel. The UV and IR data channels, `UV` and `RefIR`, play integral roles in both of the FIRE algorithms and the WELDING algorithm. Flaming events emit significant amounts of IR and NIR radiation in addition to the visible, or are both "hot" and somewhat "bright." The FIRE algorithm requires the ratio of UV to IR radiation `(UV/RefIR)` to be greater than unity. For flaming sources within the SBVS Testbed FOV, stricter criteria or a stricter "pattern" can be applied to insure accurate source classification. For the FIRE_FOV algorithm, the `UV` and `RefIR` data channels must not only have the proper ratio but also must individually exceed empirically determined thresholds. For welding nuisance sources, there is significant UV and visible radiation with little or no IR radiation, or the source is "bright" but "cold." For the WELDING algorithm, if the `UV` data channel exceeds a threshold while the `RefIR` data channel remains below another threshold, a WELDING event is declared. The potassium (766.5 nm) and guard band (1050 nm) data channels were found to be significant in both FIRE and the WELDING algorithms as part of the determination of a significant event signature or a "bright" event. As the algorithms exist after development and optimization, there appears to be no unique information between the two channels suggesting that it would be possible to remove one without seriously impacting the overall SBVS Testbed performance. However this further down selection awaits input from the other components of the VS Prototype to insure that the overall operation of the VS Prototype is not adversely impacted by internal SBVS Component modifications.

7.0 FINAL VS2 SBVS POST-PROCESSING RESULTS

7.1 Introduction

Of the 253 tests run as part of the VS2 Test Series from July to November 2003, usable SBVS Testbed data were collected from 213 of the tests. For the remaining tests, some or all of the data were unusable or not collected. Of the 213 tests with useful data, 187 tests could be unambiguously assigned to one and only one of the following source categories: FOV Flaming, Non-FOV Flaming, Smoldering, and Nuisance. The Nuisance category is divided into categorized and non-categorized Nuisances. For this analysis the only categorized Nuisance identified is Welding. The optimized, post-processing algorithms described in the previous

sections of this document were used to analyze the data from 187 tests and the results are presented below in Table 7.1 and Figures 7.1 through 7.3. The results are broken up by source type and by classification, detection, and false alarm probabilities. The two OFDs used as part of the SBVS Testbed have internal logic and processing for fire event detection. The stand-alone results for the OFDs are presented for comparison. An Excel spreadsheet of the individual results for each test can be found on the attached CD.

7.2 SBVS VS2 Results by Category

The overall performance (correct classification) results of the SBVS algorithms are listed in Table 7.1 and depicted in Figure 7.1. The FIRE event algorithm overall correctly classified / detected the flaming sources (P_{corr} / P_d = 0.883) with a P_{fa} of 0.000. These results indicate that the algorithm obtains a high level of sensitivity and classification without loosing any false alarm immunity. For the same set of tests, the FIRE_FOV event algorithm results were P_{corr} / P_d = 0.383 and P_{fa} = 0.000 respectively. The FIRE_FOV absolute detection numbers are lower than for FIRE due to the more stringent criteria for a FIRE_FOV event. The test of flaming sources includes fire sources that are both in and out of the SBVS Testbed FOV. As the name would indicate, the FIRE_FOV event is designed to specifically identify FOV fire sources, and may not detect non-FOV sources. If the test set is restricted to FOV flaming sources only, the detection results increase from P_d = 0.883 and 0.383 to 0.900 and 0.700, respectively, for the FIRE and FIRE_FOV events. The only response from any of the algorithms / OFDs to the welding sources was a P_{corr} = 0.990 for the WELDING event algorithm. The one false alarm was due to a very large flaming source that was at least partially obscured from the detectors. Positive welding source detection is a capability not demonstrated by any other algorithm or detector currently available within the Volume Sensor Prototype. The FIRE and PDSMOKE event algorithms correctly classify a significantly larger number (P_{corr} = 0.81 and 0.51 respectively) of the transitioning sources than the OFDs (P_{corr} = 0.08 to 0.16).

Table 7.1 –Volume Sensor Test Series 2 SBVS Testbed Categorized Results

		EVENT	PDSMOKE	FIRE	FIRE_FOV	WELDING	OmniGuard	EyeSpy
Flame	# of tests	50	50	50	50	50	50	50
FOV	# of alarms	47	45	45	35	2	43	38
	# correct	47	5	45	35	48	43	38
	# of false alarms	n/a [1]	45	n/a	n/a	2	n/a	n/a
	P_{corr}	0.940	0.100	0.900	0.700	0.960	0.860	0.760
	P_d	0.940	n/a	0.900	0.700	n/a	0.860	0.760
	P_{fa}	n/a	0.900	n/a	n/a	0.040	n/a	n/a
	average alarm time (sec)	99	278	147	222	225	163	188
Flame	# of tests	44	44	44	44	44	44	44
!FOV	# of alarms	44	40	38	1	1	3	2
	# correct	44	4	38	1	43	3	2
	# of false alarms	n/a	40	n/a	n/a	1	n/a	n/a
	P_{corr}	1.000	9%	0.864	0.023	0.977	0.068	0.045
	P_d	1.000	n/a	0.864	0.023	n/a	0.068	0.045
	P_{fa}	n/a	91%	n/a	n/a	0%	n/a	n/a
	average alarm time (sec)	148	261	166	260	336	330	340
Flame	P_{corr}	0.968	0.960	0.883	0.383	0.968	0.489	0.426
All	P_d	0.968	n/a	0.883	0.383	n/a	0.489	0.426
	P_{fa}	n/a	0.904	n/a	n/a	0.032	n/a	n/a
Smoldering	# of tests	50	50	50	50	50	50	50
	# of alarms	37	23	9	0	0	5	0
	# correct	37	23	41	50	50	45	50
	# of false alarms	0	0	9	0	0	5	0
	P_{corr}	0.740	0.460	0.82	1.000	1.000	0.900	1.000
	P_d	0.740	0.460	n/a	n/a	n/a	n/a	n/a
	P_{fa}	0.000	n/a	0.180	0.000	0.000	0.100	0.000
	average alarm time (sec)	601	912	1017	DNA [2]	DNA	1175	DNA
Nuisances	# of tests	43	43	43	43	43	43	43
	# of alarms	11	4	6	0	4	0	0
	# correct	32	39	37	43	43	43	43
	# of false alarms	11	4	6	0	0	0	0
	P_{corr}	0.740	0.907	0.860	1.000	1.000	1.000	1.000
	P_d	n/a	n/a	n/a	n/a	1.000 [3]	n/a	n/a
	P_{fa}	0.256	0.093	0.140	0.000	0.000	0.000	0.000
	average alarm time (sec)	117	107	172	DNA	167	DNA	DNA

[1] n/a = not applicable, a result category which does not apply to the set of tests.
[2] DNA = Did Not Alarm. No test in this set of tests generated an alarm for this category.
[3] P_d is defined as # of welding sources detected out of total # of welding sources (4 total).

Figure 7.2 depicts the probability of detection, as opposed to correctly classified (as in the last paragraph), for the various categories of tests. Figure 7.3 depicts the event algorithm probability of false alarm broken up by source category. The sparseness of results in Figures 7.2 and 7.3 is due to the use of the following definitions, not lack of algorithm response. The P_d for nuisance sources is defined as exactly zero except for welding nuisance sources and the WELDING event algorithm. The P_d for cross detections is also defined as exactly zero. PDSMOKE may not have detections for pure flaming sources and the same is true for the FIRE and FIRE_FOV events for smoldering sources. Any "detection" of these events is classified as a false alarm. As will be discussed in Section 8, while statistics for this set of definitions are easily computed, they count good detections (source versus nuisance) with incorrect classifications (smoldering versus flaming) as false alarms.

Looking at positive source detection (P_d, Figure 7.2), the SBVS event detection algorithms show significant sensitivity compared to the OFDs. This sensitivity comes with somewhat reduced false alarm immunity. The PDSMOKE event algorithm demonstrated modest source detection with a $P_d = 0.46$ for the smoldering sources, an impressive result considering that the SBVS Testbed is designed to detect light emission from sources and smoke does not emit radiation at the detection wavelengths of the SBVS Testbed sensors. The detection of smoke is based on changes in the incident light on the 5900 Å detector caused by the smoke due to either scattering or reflection of ambient room light into or away from the detector. Due to the simplicity of the PDSMOKE event algorithm, it is susceptible to "bright" nuisance sources that generate a large amount of visible light, such as welding, the introduction of new light sources, and even large fires. The PDSMOKE event algorithm demonstrated good false alarm rejection with a $P_{fa} = 0.093$ for the nuisance sources. The PDSMOKE event algorithm generated an alarm for most of the flaming sources with a $P_{fa} = 0.900$, which are technically false alarms, as defined. Since there was actually a flaming source in the space which may have generated some smoke during the test and certainly generated light from the flaming source, this result should be considered a successful DC event detection with the caveat that the source was not properly classified between flaming and smoldering. The WELDING event algorithm detected all of the welding sources in the test series, a P_d of 1.000. For flaming sources the FIRE and FIRE_FOV event algorithms detected the sources with $P_d = 0.883$ and 0.383, respectively, of the flaming sources. As a benchmark, the OFDs detected approximately half of the flaming sources, $P_d = 0.45$, on par with the FIRE_FOV event algorithm. The FIRE event algorithm detected almost twice as many of the flaming sources. This increased sensitivity does not come without penalty. For the FIRE event algorithm, false alarm probabilities of $P_{fa} = 0.18$ for misclassification of smoldering sources as flaming and $P_{fa} = 0.14$ for classifying nuisance sources as a flaming source resulted. Again, the cross-detection results are correct detections (source versus nuisance) but incorrect classification (flaming versus smoldering).

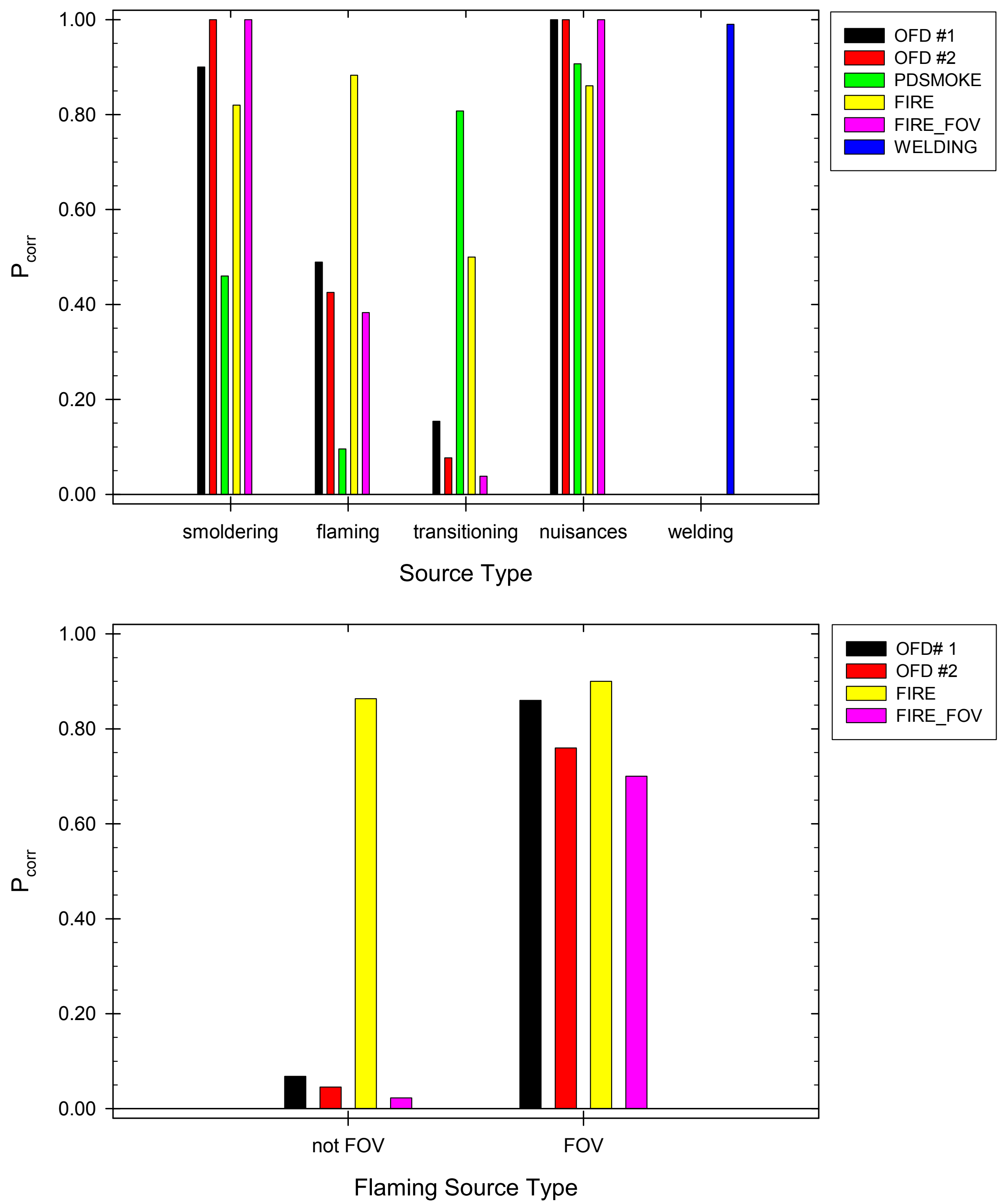


Fig. 7.1 – Categorized Probability of Correct Classification for VS2 Tests for SBVS Events and OFDs

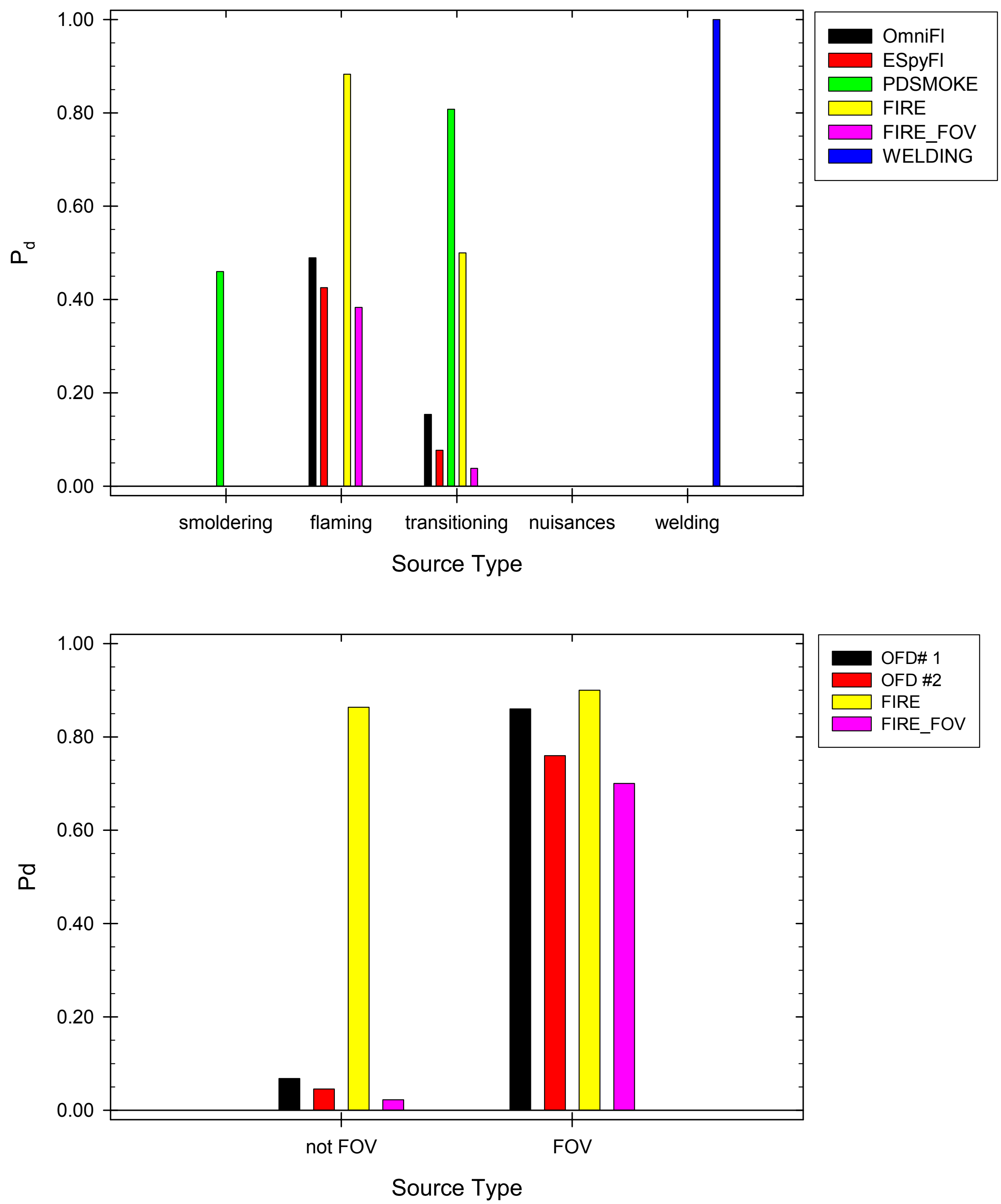


Fig. 7.2 – Categorized Probability of Detection for VS2 Tests for SBVS Events and OFDs

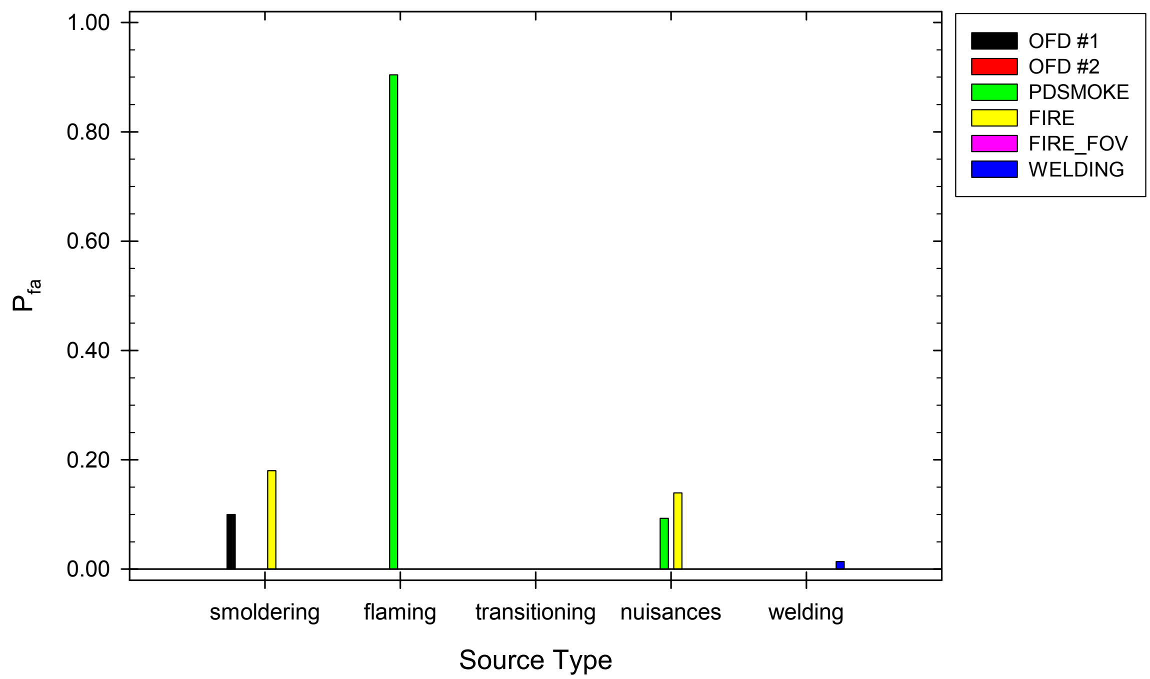


Fig. 7.3 – Categorized Probability of False Alarm for VS2 Tests for SBVS Events and OFDs

8.0 DISCUSSION

The event detection algorithms developed for data collected from the SBVS Testbed during the VS2 Test Series show dramatic detection sensitivity and significant DC source versus nuisance classification ability. For partially or completely obscured flaming sources and for smoldering sources, the SBVS event detection algorithms offer significant increases in detection sensitivity over COTS OFDs while maintaining the ability to reject common nuisance sources which are problematic for COTS and VID-based smoke detection systems. Positive detection of arc welding and similar "bright" nuisance sources offers a significant new capability to the overall Volume Sensor Prototype not found in currently available COTS systems. For flaming sources within the sensor's FOV the SBVS event detections algorithms offer similar performace to that of mature COTS OFDs.

Algorithms were developed to classify flaming sources both in and out of the sensor's FOV with a high level of success. The FIRE (non-FOV) algorithm does exhibit high false alarm probabilities (Pfa = 0.140) for nuisance sources. These false alarms are the result of nuisance sources that emit a great deal of light, or are "bright." As evidenced by the results of the FIRE_FOV algorithm, one can develop criteria to reduce / eliminate the false alarms but at the sacrifice of detection sensitivity. Continued development of the FIRE event algorithm, perhaps in concert with the other elements of the VS program, may lead to improved nuisance rejection without loss of detection sensitivity. A third algorithm was developed for indirect detection of smoke buildup in the sensor FOV. Taking advantage of the longer time scale changes in ambient room light measured at the SBVS Testbed by the 5900 Å detector, smoke was detected from

almost half of the smoldering test sources, $P_d = 0.460$. The performance of this algorithm is contingent on the available room light and the light source / smoke / detector geometry. Also the algorithm is fairly rudimentary even in comparison to the other SBVS event algorithms, as indicated by the cross-detection $P_{fa} = 0.900$ for flaming sources in this analysis. The majority of false alarms from the PDSMOKE algorithm are due to “bright” emission from both flaming and nuisance sources. As an example, a bright flashlight shining directly into the 5900 Å detector will cause a false smoke alarm. This is also true, to a lesser extent, for the FIRE algorithm. In the case of smoldering sources and the PDSMOKE event algorithm, the nuisance sources are typically fast and transient in nature. The application of a long persistence requirement should reduce the false alarm count. For nuisances like welding which can cause multiple simultaneous algorithm detections, the addition of upper-bound values on the non-5900 Å detector values would most likely improve the PDSMOKE event algorithm. In the context of the current VS Prototype and the VS Data Fusion Algorithms [10], the WELDING event overrides any other alarms, so this issue does not affect the performance of the VS as a whole. The WELDING event algorithm demonstrated near perfect performance, only misclassifying one source out of the 187 tests. This source was a large non-FOV source that generated an uncharacteristic amount of UV radiation, causing the WELDING event to trigger. A generic EVENT event was also developed. This event is used in part as a trigger for the other four SBVS event algorithms. If the EVENT event has not alarmed, the other four events are blocked. The output from this algorithm could also be used by other algorithms, either within the SBVS or within the VS Prototype as a whole.

9.0 CONCLUSION

A robust set of DC event detection algorithms was developed to make use of the data generated by the SBVS Testbed sensor suite. These algorithms detect DC events such as flaming and smoldering sources, both within and outside of the SBVS Testbed FOV. A positive nuisance classification event was also developed for arc welding and similar sources. A generic trigger event was also developed as part of the other events and is available for future algorithms.

These algorithms were tested against a data set composed of 187 tests conducted during the VS 2 Test Series. Performance comparable to that of COTS OFDs was achieved for the individual algorithms and flaming sources in the SBVS Testbed FOV. Superior performance was demonstrated for sources that were partially or completely obscured from the SBVS Testbed FOV. An algorithm for indirectly detecting smoke within the compartment demonstrated modest performance. While source detection and nuisance / source classification were good ($P_{corr} = 0.80$ and higher), cross detection classification errors (for example, flaming sources detected as smoldering and vice versa) remain an area for future improvement.

10.0 ACKNOWLEDGEMENTS

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A.0 APPENDIX A – SBVS TESTBED DATA FILE EXAMPLES

A.1 VS2A DataLogger Files

The following sections contain the first fifteen lines of each data log file for the test VS2-179.

A.1.1 VS2A DataLogger DAQ File

VS2-179 - Oct282003_102659.dat

Log_Time	5900A	7665A	10500A	PbSe	PMT260	PMT307	OmniFl	ESpyFl
10:26:59:473	0.063	0.013	0.008	-0.002	-0.075	-0.030	0	0
10:26:59:563	0.063	0.013	0.008	-0.002	-0.077	-0.031	0	0
10:26:59:660	0.063	0.013	0.008	-0.002	-0.076	-0.030	0	0
10:26:59:762	0.063	0.013	0.008	-0.002	-0.076	-0.030	0	0
10:26:59:859	0.063	0.013	0.008	-0.002	-0.075	-0.030	0	0
10:26:59:961	0.063	0.013	0.008	-0.002	-0.076	-0.030	0	0
10:27:00:063	0.063	0.013	0.008	-0.002	-0.077	-0.030	0	0
10:27:00:160	0.063	0.013	0.008	-0.002	-0.076	-0.029	0	0
10:27:00:262	0.063	0.013	0.008	-0.002	-0.075	-0.029	0	0
10:27:00:363	0.063	0.013	0.008	-0.002	-0.076	-0.029	0	0
10:27:00:461	0.063	0.013	0.008	-0.002	-0.076	-0.029	0	0
10:27:00:563	0.063	0.013	0.008	-0.002	-0.075	-0.029	0	0
10:27:00:660	0.063	0.013	0.008	-0.002	-0.075	-0.029	0	0
10:27:00:762	0.063	0.013	0.008	-0.002	-0.077	-0.029	0	0

…

A.1.2 VS2A DataLogger OmniGuard File

VS2-179 - Oct282003_102659.omni

Omni_Time	UV	Ref IR	Fire	OmniFlO	OmniFaO
10:26:59:832	00	6400	00	0	0
10:27:00:863	00	6400	00	0	0
10:27:01:934	00	6400	00	0	0
10:27:02:957	00	6400	00	0	0
10:27:04:035	00	6400	00	0	0
10:27:05:059	00	6400	00	0	0
10:27:06:129	00	6400	00	0	0
10:27:07:152	00	6400	00	0	0
10:27:08:234	00	6400	00	0	0
10:27:09:246	00	6400	00	0	0
10:27:10:336	00	6400	00	0	0
10:27:11:348	00	6400	00	0	0
10:27:12:430	00	6400	00	0	0
10:27:13:441	00	6400	00	0	0

…

A.1.3 VS2A DataLogger EyeSpy File

VS2-179 - Oct282003_102659.spy

Spy_Time	BB_DC	Right_DC	Left_DC	BB_AC	Right_AC	Left_AC	Therm.	UV_Count	Alarm	Fault
10:27:00:051	22	21	20	128	129	129	109	0	0	0
10:27:01:031	22	21	20	128	129	129	109	0	0	0
10:27:02:043	22	21	20	128	129	129	109	0	0	0
10:27:03:047	22	21	20	128	129	129	109	0	0	0
10:27:04:059	22	21	20	128	129	129	109	0	0	0
10:27:05:070	22	22	20	128	129	129	109	0	0	0
10:27:06:051	22	21	20	128	129	129	109	0	0	0
10:27:07:051	22	21	20	128	129	129	109	0	0	0
10:27:08:063	21	21	20	128	129	129	109	0	0	0
10:27:09:137	22	21	20	128	129	129	109	0	0	0

```
10:27:10:047       22       21       20      126      129      129      109        0        0        0
10:27:11:059       21       21       20      128      129      129      109        0        0        0
10:27:12:059       22       22       21      128      129      129      109        0        0        0
10:27:13:129       22       22       21      126      129      129      109        0        0        0
…
```

A.2 VS2B FPDataLogger Files

The following sections contain the first fifteen lines of each data log file for the test VS2-202.

A.2.1 VS2B DataLogger DAQ file

```
VS2-202 – Nov102003_170704.dat
  Log_Time      5900A    7665A   10500A     PbSe   PMT260   PMT307   OmniFl   OmniFa   ESpyFl
17:07:04:230    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:04:332    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:04:434    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:04:531    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:04:734    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:04:832    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:04:934    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:05:031    0.085    0.023    0.004    0.000   -0.007   -0.278        1        1        1
17:07:05:234    0.085    0.023    0.004    0.000   -0.007   -0.279        1        1        1
17:07:05:336    0.085    0.023    0.004    0.000   -0.007   -0.279        1        1        1
17:07:05:434    0.085    0.023    0.004    0.000   -0.007   -0.279        1        1        1
17:07:05:535    0.085    0.023    0.004    0.000   -0.007   -0.279        1        1        1
17:07:05:734    0.085    0.023    0.004    0.000   -0.007   -0.279        1        1        1
17:07:05:836    0.085    0.023    0.004    0.000   -0.007   -0.279        1        1        1
…
```

A.2.2 VS2B DataLogger OmniGaurd file

```
VS2-202 – Nov102003_170704.omni
Omni_Time         UV   Ref IR     Fire  OmniFlO  OmniFaO
```

{Note: OmniGuard was damaged during reconfiguration from VS2A to VS2B, unit could not be repaired prior to completion of VS2B tests.}

A.2.3 VS2B DataLogger EyeSpy file

```
VS2-202 – Nov102003_170704.spy
  Spy_Time      BB_DC Right_DC  Left_DC    BB_AC Right_AC  Left_AC   Therm. UV_Count    Alarm    Fault
17:07:04:715       21       21       20      128      129      129       88        0        0        0
17:07:05:715       21       21       20      128      129      129       88        0        0        0
17:07:06:727       21       21       20      128      129      129       88        0        0        0
17:07:07:695       21       21       20      128      129      129       88        0        0        0
17:07:08:719       21       21       20      128      129      129       88        0        0        0
17:07:09:719       21       21       20      128      129      129       88        0        0        0
17:07:10:730       21       21       20      128      129      129       88        0        0        0
17:07:11:723       21       21       20      128      129      129       88        0        0        0
17:07:12:723       21       21       20      128      129      129       88        0        0        0
17:07:13:695       21       21       20      128      129      129       88        0        0        0
17:07:14:707       21       21       20      128      129      129       88        0        0        0
17:07:15:727       21       21       20      128      129      129       88        0        0        0
17:07:16:730       21       21       20      128      129      129       88        0        0        0
17:07:17:730       21       21       20      128      129      129       88        0        0        0
```

B.0 APPENDIX B – SBVS TESTBED PCA FILE EXAMPLE

The following example contains the first fifteen lines of a common format, normalized data file (PCA file). The file is composed of main columns that have been broken into several blocks for legibility. Some columns of white space have been omitted for clarity as well.

VS2-179 - Oct282003_102659_PCA.txt

Columns 1 through 108

Log_Time	5900A	7665A	10500A	PbSe	PMT260	PMT307	OmniFl	ESpyFl
10:26:59.859	0.0000	0.0000	0.0000	0.0000	-0.0016	-0.0021	0	0
10:27:00.863	0.0000	0.0000	0.0000	0.0000	-0.0012	-0.0021	0	0
10:27:01.863	0.0000	0.0000	0.0000	0.0000	-0.0018	-0.0019	0	0
10:27:02.867	0.0000	0.0000	0.0000	0.0000	-0.0010	-0.0015	0	0
10:27:03.867	0.0000	0.0000	0.0000	0.0000	-0.0008	-0.0011	0	0
10:27:04.867	0.0000	0.0000	0.0000	0.0000	-0.0006	-0.0003	0	0
10:27:05.871	0.0000	0.0000	0.0000	0.0000	0.0002	0.0007	0	0
10:27:06.859	0.0000	0.0000	0.0000	0.0000	0.0016	0.0017	0	0
10:27:07.863	0.0000	0.0000	0.0000	0.0000	0.0020	0.0025	0	0
10:27:08.863	0.0000	0.0000	0.0000	0.0000	0.0030	0.0039	0	0
10:27:09.867	0.0000	0.0000	0.0000	0.0000	0.0040	0.0055	0	0
10:27:10.867	0.0000	0.0000	0.0000	0.0000	0.0048	0.0063	0	0
10:27:11.867	0.0000	0.0000	0.0000	0.0000	0.0062	0.0079	0	0
10:27:12.871	0.0000	0.0000	0.0000	0.0000	0.0072	0.0093	0	0

Columns 114 through 185

Omni_Time	UV	Ref_IR	Fire	OmniFlO	OmniFaO
10:26:59.832	0.0000	0.0000	0.0000	0	0
10:27:00.863	0.0000	0.0000	0.0000	0	0
10:27:01.934	0.0000	0.0000	0.0000	0	0
10:27:02.957	0.0000	0.0000	0.0000	0	0
10:27:04.035	0.0000	0.0000	0.0000	0	0
10:27:05.059	0.0000	0.0000	0.0000	0	0
10:27:06.129	0.0000	0.0000	0.0000	0	0
10:27:07.152	0.0000	0.0000	0.0000	0	0
10:27:08.234	0.0000	0.0000	0.0000	0	0
10:27:09.246	0.0000	0.0000	0.0000	0	0
10:27:10.336	0.0000	0.0000	0.0000	0	0
10:27:11.348	0.0000	0.0000	0.0000	0	0
10:27:12.430	0.0000	0.0000	0.0000	0	0
10:27:13.441	0.0000	0.0000	0.0000	0	0

Columns 190 through 297

Spy_Time	BB_DC	Right_DC	Left_DC	BB_AC	Right_AC	Left_AC	Therm.	UV_Count
10:27:00.051	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:01.031	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:02.043	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:03.047	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:04.059	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:05.070	0.0000	0.0039	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:06.051	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:07.051	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:08.063	-0.0039	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:09.137	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:10.047	0.0000	0.0000	0.0000	-0.0157	0.0000	0.0000	0.4275	0.0000
10:27:11.059	-0.0039	0.0000	0.0000	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:12.059	0.0000	0.0039	0.0039	0.0000	0.0000	0.0000	0.4275	0.0000
10:27:13.129	0.0000	0.0039	0.0039	-0.0157	0.0000	0.0000	0.4275	0.0000

Columns 305 through 363

Alarm	Fault	DAQStart_Time	DAQStart_Limits
0	0	10:26:59	-1000000
0	0	10:26:59	1000000
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		
0	0		

C.0 APPENDIX C – SBVS TESTBED PCA RESULTS

C.1. PCA Results

The complete PCA results for the Candidate Tests are given in this section. This Appendix is provided in support of the main text. Results are broken up by test. See the main text for discussion. Source which are not in the SBVS Testbed Field-of-View (FOV) or did not transition to flaming (Trans) are indicated by !FOV and !Trans. The "!" symbol is shorthand for "Not." The maximum number of allowed PCs was limited to ten for this analysis.

```
VS2 Candidate Test Sources and Nuisances
Subset used for PCA Analysis
```

```
Aug202003_151703, Test VS2-064, Smoldering Laundry, FOV, !Trans
```

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
_5900A	0.783	0.009	0.525	0.109	0.000	0.000	0.000	0.000	0.000
_7665A	0.969	-0.012	0.062	-0.026	0.000	0.000	0.000	0.000	0.000
_10500A	0.945	-0.012	-0.104	-0.056	0.000	0.000	0.000	0.000	0.000
PbSe	-0.112	-0.041	0.608	-0.188	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Ref_IR	0.350	0.048	0.807	0.181	0.000	0.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Right_DC	0.000	0.803	-0.057	-0.005	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.015	0.801	0.048	-0.008	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.028	-0.018	-0.054	0.962	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000

```
Jul232003_112202, Test VS2-007, Flaming Bedding, !FOV, Trans
```

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
_5900A	0.782	-0.039	0.077	-0.030	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.769	-0.043	0.161	0.073	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.656	0.050	-0.269	-0.055	0.000	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
BB_DC	-0.039	0.806	-0.187	0.017	0.000	0.000	0.000	0.000	0.000	0.000
Right_DC	0.028	0.046	0.920	-0.013	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	0.003	0.740	0.269	-0.023	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.011	-0.004	-0.011	0.996	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

```
Jul232003_151943, Test VS2-010, Flaming Boxes with Paper Filling, FOV, Trans
```

	PC1	PC2	PC3	PC4
_5900A	0.003	0.063	-0.929	0.000
_7665A	0.842	0.264	-0.416	0.000
_10500A	0.879	0.256	-0.356	0.000
PbSe	0.000	0.000	0.000	1.000
UV	0.661	0.165	-0.601	0.000
Ref_IR	0.927	0.244	-0.247	0.000
BB_DC	0.960	0.231	0.046	0.000
Right_DC	0.930	0.178	0.253	0.000
Left_DC	0.949	0.209	0.144	0.000
BB_AC	0.262	0.858	-0.057	0.000
Right_AC	0.247	0.918	-0.079	0.000
Left_AC	0.209	0.945	-0.084	0.000
UV_Count	0.633	0.185	-0.304	0.000

Jul292003_095917, Test VS2-019, Flaming Boxes with Paper Filling, !FOV, Trans

	PC1	PC2	PC3	PC4	PC5
_5900A	-0.649	-0.269	0.000	0.000	0.000
_7665A	-0.002	-0.979	0.000	0.000	0.000
_10500A	0.112	-0.981	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000
UV	0.000	0.000	0.000	1.000	0.000
Ref_IR	0.757	-0.626	0.000	0.000	0.000
BB_DC	0.894	-0.292	0.000	0.000	0.000
Right_DC	0.940	-0.005	0.000	0.000	0.000
Left_DC	0.964	-0.099	0.000	0.000	0.000
BB_AC	0.524	-0.288	0.000	0.000	0.000
Right_AC	0.493	0.115	0.000	0.000	0.000
Left_AC	0.357	-0.139	0.000	0.000	0.000
UV_Count	0.000	0.000	1.000	0.000	0.000

Oct232003_165200, Test VS2-165, Smoldering Cables, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
_5900A	0.861	-0.003	0.000	-0.056	0.000	0.000	0.000	0.000	0.000
_7665A	0.899	0.004	-0.004	-0.011	0.000	0.000	0.000	0.000	0.000
_10500A	0.897	0.014	-0.001	0.073	0.000	0.000	0.000	0.000	0.000
PbSe	0.006	-0.008	-0.004	0.908	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
BB_DC	0.013	-0.802	-0.081	0.030	0.000	0.000	0.000	0.000	0.000
Right_DC	0.014	-0.039	0.755	-0.270	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.023	-0.796	0.097	-0.027	0.000	0.000	0.000	0.000	0.000
BB_AC	0.018	-0.023	-0.655	-0.319	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
UV_Count	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Oct242003_095036, Test VS2-168, Smoldering Mattress, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
_5900A	0.977	0.003	0.042	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.991	0.010	0.035	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.974	0.019	0.031	0.000	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
BB_DC	0.070	0.039	0.668	0.000	0.000	0.000	0.000	0.000	0.000
Right_DC	0.053	0.745	0.227	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.003	-0.015	0.729	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.028	0.792	-0.181	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000

Oct272003_154425, Test VS2-177, Smoldering Laundry, !FOV, Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
_5900A	0.906	-0.023	-0.018	0.094	0.000	0.000	0.000	0.000
_7665A	0.898	-0.026	-0.064	0.098	0.000	0.000	0.000	0.000
_10500A	0.816	0.084	-0.014	-0.015	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Ref_IR	0.483	-0.014	0.084	-0.179	0.000	0.000	0.000	0.000
BB_DC	-0.016	0.175	-0.832	0.016	0.000	0.000	0.000	0.000
Right_DC	0.041	0.724	-0.039	0.009	0.000	0.000	0.000	0.000
Left_DC	-0.016	0.572	-0.278	-0.041	0.000	0.000	0.000	0.000
BB_AC	-0.025	0.602	0.490	0.039	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Left_AC	-0.015	-0.010	0.006	0.975	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000

Oct272003_165406, Test VS2-178, Smoldering Trash, !FOV, Trans

	PC1	PC2	PC3	PC4	PC5	PC6
_5900A	0.964	-0.081	-0.007	0.000	0.000	0.000
_7665A	0.965	-0.013	-0.027	0.000	0.000	0.000
_10500A	0.887	0.132	-0.080	0.000	0.000	0.000
PbSe	0.091	0.302	-0.209	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000
Ref_IR	0.730	-0.212	0.029	0.000	0.000	0.000
BB_DC	0.077	-0.636	-0.051	0.000	0.000	0.000
Right_DC	0.098	-0.648	-0.150	0.000	0.000	0.000
Left_DC	0.550	-0.520	0.126	0.000	0.000	0.000
BB_AC	0.015	-0.113	-0.640	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.034	-0.057	0.719	0.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000

Oct282003_104335, Test VS2-180, Smoldering Wire, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
_5900A	-0.058	0.001	-0.916	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	-0.130	-0.697	0.290	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Right_DC	0.753	0.043	-0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.132	0.722	0.277	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	0.746	-0.046	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Oct282003_111335, Test VS2-181, Smoldering Circuit Boards, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
_5900A	0.365	-0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
_10500A	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Right_DC	-0.682	-0.311	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	0.087	-0.947	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.695	0.119	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Sep042003_164111, Test VS2-096, Smoldering Laundry, FOV, Trans

	PC1	PC2	PC3
_5900A	0.097	-0.912	-0.108
_7665A	0.823	-0.501	0.194
_10500A	0.865	-0.417	0.225
PbSe	-0.141	-0.465	0.186
UV	0.301	-0.872	-0.047
Ref_IR	0.677	-0.692	0.104
BB_DC	0.933	-0.079	0.268
Right_DC	0.866	0.160	0.273

Left_DC	0.893	0.066	0.294
BB_AC	0.361	-0.065	0.857
Right_AC	0.221	-0.020	0.937
Left_AC	0.239	-0.045	0.929
UV_Count	0.787	-0.159	0.131

Sep052003_154457, Test VS2-102, Flaming Wood Crib, !FOV, Trans

	PC1	PC2	PC3	PC4
_5900A	0.840	-0.292	0.073	-0.088
_7665A	0.950	-0.236	0.049	-0.022
_10500A	0.951	-0.236	0.047	-0.017
PbSe	0.097	-0.017	0.020	0.859
UV	0.863	-0.107	-0.152	0.155
Ref_IR	0.782	-0.076	-0.065	0.272
BB_DC	0.696	-0.262	0.372	-0.180
Right_DC	0.196	-0.065	0.762	-0.163
Left_DC	-0.116	0.001	0.658	0.392
BB_AC	0.298	-0.873	0.055	-0.032
Right_AC	0.194	-0.950	0.052	-0.002
Left_AC	0.174	-0.924	0.018	0.057
UV_Count	0.612	-0.103	0.213	-0.013

Sep082003_182121, Test VS2-114, Smoldering Laundry, !FOV, Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
_5900A	0.884	-0.200	-0.017	0.000	0.000	0.000	0.000	0.000
_7665A	0.935	0.131	-0.055	0.000	0.000	0.000	0.000	0.000
_10500A	0.531	0.654	-0.053	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Ref_IR	0.803	0.438	-0.046	0.000	0.000	0.000	0.000	0.000
BB_DC	-0.122	0.109	-0.837	0.000	0.000	0.000	0.000	0.000
Right_DC	0.070	0.012	-0.328	0.000	0.000	0.000	0.000	0.000
Left_DC	0.059	0.844	-0.115	0.000	0.000	0.000	0.000	0.000
BB_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	-0.092	0.433	0.424	0.000	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Sep182003_133353, Test VS2-120, Flaming Trash Can, !FOV, Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
_5900A	0.011	-0.005	0.913	0.000	0.000	0.000	0.000
_7665A	-0.076	0.917	0.054	0.000	0.000	0.000	0.000
_10500A	-0.015	0.930	-0.043	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Ref_IR	0.824	0.162	-0.321	0.000	0.000	0.000	0.000
BB_DC	0.245	-0.055	-0.317	0.000	0.000	0.000	0.000
Right_DC	0.762	-0.066	0.214	0.000	0.000	0.000	0.000
Left_DC	0.886	-0.100	0.117	0.000	0.000	0.000	0.000
BB_AC	0.127	-0.016	0.258	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.561	-0.039	0.016	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000

Sep182003_141133, Test VS2-121, Flaming Trash Can, FOV, Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
_5900A	0.948	-0.112	-0.061	-0.046	0.068	0.000	0.000	0.000	0.000
_7665A	0.923	0.130	-0.103	-0.054	0.087	0.000	0.000	0.000	0.000
_10500A	0.004	0.892	-0.058	-0.037	0.059	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Ref_IR	-0.132	0.830	0.062	-0.022	-0.066	0.000	0.000	0.000	0.000
BB_DC	-0.011	0.005	-0.030	-0.033	-0.968	0.000	0.000	0.000	0.000
Right_DC	0.222	0.109	0.083	-0.421	-0.131	0.000	0.000	0.000	0.000
Left_DC	0.666	-0.224	0.191	0.008	-0.168	0.000	0.000	0.000	0.000
BB_AC	-0.002	0.006	0.973	-0.025	0.030	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.114	0.051	0.056	0.914	-0.087	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000

Sep232003_145302, Test VS2-126 (subsitute for VS2-223), Smoldering Cables, FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
_5900A	0.926	-0.040	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.910	-0.039	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.694	0.042	0.000	0.000	0.000	0.000	0.000	0.000
PbSe	0.848	0.020	0.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Right_DC	-0.095	0.696	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.093	0.698	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.106	-0.287	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Left_AC	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

Sep242003_100748, Test VS2-131, People Working, ? FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10	PC11
_5900A	0.061	0.666	0.381	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
_10500A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
BB_DC	0.825	-0.002	0.124	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_DC	0.063	0.029	-0.863	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	0.800	0.009	-0.195	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	0.044	-0.758	0.298	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Sep242003_104803, Test VS2-133, Aerosol Spray, ? FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
_5900A	-0.168	0.636	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.031	0.740	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Right_DC	0.842	-0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	0.844	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.097	-0.490	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
UV_Count	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Sep242003_140145, Test VS2-136, Burnt Toast, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
_5900A	0.937	-0.033	-0.109	-0.031	0.000	0.000	0.000	0.000	0.000
_7665A	0.947	0.007	0.035	0.029	0.000	0.000	0.000	0.000	0.000

_10500A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
PbSe	-0.010	0.038	-0.684	-0.063	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Ref_IR	0.059	-0.160	-0.634	0.269	0.000	0.000	0.000	0.000	0.000
BB_DC	0.011	0.771	0.059	0.086	0.000	0.000	0.000	0.000	0.000
Right_DC	0.026	0.155	-0.468	-0.145	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.038	0.793	-0.153	-0.073	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.005	0.038	0.048	0.947	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Sep242003_144239, Test VS2-137, Welding, FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
_5900A	0.735	-0.034	0.109	0.000	0.000	0.000	0.000	0.000
_7665A	0.953	-0.018	-0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.958	-0.020	-0.006	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
UV	0.719	-0.038	-0.141	0.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
BB_DC	-0.046	0.921	-0.001	0.000	0.000	0.000	0.000	0.000
Right_DC	-0.037	-0.016	0.989	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.042	0.922	-0.015	0.000	0.000	0.000	0.000	0.000
BB_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Right_AC	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Left_AC	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
UV_Count	0.744	-0.020	-0.019	0.000	0.000	0.000	0.000	0.000

Sep252003_065636, Test VS2-141, Sunlight, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
_5900A	0.825	0.031	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.839	-0.028	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.731	0.035	0.000	0.000	0.000	0.000	0.000	0.000
PbSe	0.579	-0.240	0.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
BB_DC	0.039	-0.192	0.000	0.000	0.000	0.000	0.000	0.000
Right_DC	-0.091	0.727	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
BB_AC	0.091	0.652	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Left_AC	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

Sep302003_082827, Test VS2-145, White Shirt Waving, ? FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
_5900A	0.918	-0.047	-0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.920	0.032	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
PbSe	0.062	0.815	-0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Right_DC	-0.032	-0.013	0.801	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	0.081	-0.019	0.791	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.075	0.811	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000

Sep302003_103617, Test VS2-152, Toast, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9

_5900A	0.979	-0.024	-0.061	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.981	0.003	-0.033	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
PbSe	-0.006	-0.077	0.706	0.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
BB_DC	0.024	0.807	-0.032	0.000	0.000	0.000	0.000	0.000	0.000
Right_DC	0.009	0.064	0.728	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.041	0.809	0.065	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	0.022	-0.012	-0.177	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

Sep302003_132510, Test VS2-154, Welding (Stick), !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
_5900A	0.966	0.069	0.001	0.000	0.000	0.000	0.000	0.000
_7665A	0.955	0.242	-0.008	0.000	0.000	0.000	0.000	0.000
_10500A	0.746	0.522	-0.008	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
UV	0.047	0.842	0.012	0.000	0.000	0.000	0.000	0.000
Ref_IR	0.296	0.767	0.083	0.000	0.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Right_DC	0.004	-0.147	0.847	0.000	0.000	0.000	0.000	0.000
Left_DC	0.007	-0.162	-0.537	0.000	0.000	0.000	0.000	0.000
BB_AC	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
Left_AC	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
UV_Count	0.175	0.751	-0.002	0.000	0.000	0.000	0.000	0.000

Sep302003_134829, Test VS2-155, Cutting Steel, FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
_5900A	0.286	0.013	0.688	-0.091	0.000	0.000	0.000	0.000	0.000
_7665A	0.918	0.058	0.301	0.065	0.000	0.000	0.000	0.000	0.000
_10500A	0.946	0.063	0.005	0.026	0.000	0.000	0.000	0.000	0.000
PbSe	-0.126	-0.017	0.106	0.886	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Ref_IR	0.008	-0.026	-0.822	-0.011	0.000	0.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Right_DC	0.058	0.850	-0.025	0.006	0.000	0.000	0.000	0.000	0.000
Left_DC	0.041	0.847	0.068	-0.008	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.145	-0.011	0.126	-0.458	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Sep302003_141409, Test VS2-156, Cutting Steel, !FOV, !Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
_5900A	0.536	0.019	-0.439	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.944	0.011	0.016	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.933	0.030	0.158	0.000	0.000	0.000	0.000	0.000	0.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Ref_IR	-0.104	0.141	0.826	0.000	0.000	0.000	0.000	0.000	0.000
BB_DC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Right_DC	-0.055	-0.750	-0.100	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	0.015	-0.768	0.154	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.112	0.118	-0.378	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000

Sep302003_151718, Test VS2-158, Smoldering Monitor, !FOV,!Trans

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
_5900A	0.963	-0.014	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_7665A	0.962	-0.021	-0.017	0.000	0.000	0.000	0.000	0.000	0.000	0.000
_10500A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
PbSe	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
UV	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
Ref_IR	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
BB_DC	-0.016	0.812	-0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_DC	-0.008	-0.004	0.765	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Left_DC	-0.013	0.813	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000
BB_AC	-0.007	-0.001	0.764	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000
Left_AC	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
UV_Count	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000

C.2. PCA Reprocessing Using Reduced Data Channel Subset

The PCA results for the Candidate Tests using the down-selected data channels are given in this section. Based on the initial analysis, the number of data channels required was reduced to five; the three photodiodes (PDs), the UV, and the IR channels. This Appendix is provided in support of the main text. Results are broken up by test. See the main text for discussion. Source which are not in the SBVS Testbed Field-of-View (FOV) or did not transition to flaming (Trans) are indicated by !FOV and !Trans. The "!" symbol is shorthand for "Not."

VS2 Candidate Test Sources and Nuisances
Subset used for PCA Analysis

Maxiumum of 5 PCA components, detection threshold set at 0.001

Aug202003_151703, Test VS2-064, Smoldering Laundry, FOV, !Trans

	PC1	PC2	PC3
_5900A	0.577	0.781	0.000
_7665A	0.948	0.267	0.000
_10500A	0.984	0.071	0.000
Ref_IR	0.056	0.984	0.000
UVA	0.000	0.000	1.000

Jul232003_112202, Test VS2-007, Flaming Bedding, !FOV, Trans

	PC1	PC2
_5900A	0.787	0.000
_7665A	0.776	0.000
_10500A	0.642	0.000
Ref_IR	0.000	1.000

Jul232003_151943, Test VS2-010, Flaming Boxes with Paper Filling, FOV, Trans

	PC1
_5900A	0.484
_7665A	0.980
_10500A	0.969
Ref_IR	0.953
UV	0.913

Jul292003_095917, Test VS2-019, Flaming Boxes with Paper Filling, !FOV, Trans

	PC1	PC2
_5900A	0.071	-0.971

_7665A	0.963	-0.157
_10500A	0.989	-0.073
Ref_IR	0.790	0.488

Oct232003_165200, Test VS2-165, Smoldering Cables, !FOV, !Trans

	PC1	PC2	PC3
_5900A	0.860	0.000	0.000
_7665A	0.900	0.000	0.000
_10500A	0.898	0.000	0.000
Ref_IR	0.000	0.000	1.000
UV	0.000	1.000	0.000

Oct242003_095036, Test VS2-168, Smoldering Mattress, !FOV, !Trans

	PC1	PC2
_5900A	0.977	0.000
_7665A	0.992	0.000
_10500A	0.976	0.000
Ref_IR	0.000	1.000

Oct272003_154425, Test VS2-177, Smoldering Laundry, !FOV, Trans

	PC1
_5900A	0.909
_7665A	0.902
_10500A	0.817
Ref_IR	0.474

Oct272003_165406, Test VS2-178, Smoldering Trash, !FOV, Trans

	PC1
_5900A	0.962
_7665A	0.970
_10500A	0.898
Ref_IR	0.744

Oct282003_104335, Test VS2-180, Smoldering Wire, !FOV, !Trans

	PC1	PC2	PC3
_5900A	0.709	0.000	0.000
_7665A	-0.709	0.000	0.000
_10500A	0.000	0.000	1.000
Ref_IR	0.000	1.000	0.000

Oct282003_111335, Test VS2-181, Smoldering Circuit Boards, !FOV, !Trans

	PC1	PC2	PC3	PC4
_5900A	0.000	1.000	0.000	0.000
_7665A	0.000	0.000	1.000	0.000
_10500A	0.000	0.000	0.000	1.000
Ref_IR	1.000	0.000	0.000	0.000

Sep042003_164111, Test VS2-096, Smoldering Laundry, FOV, Trans

	PC1
_5900A	0.684
_7665A	0.969
_10500A	0.944
Ref_IR	0.980

Sep052003_154457, Test VS2-102, Flaming Wood Crib, !FOV, Trans

	PC1
_5900A	0.914
_7665A	0.981
_10500A	0.982
Ref_IR	0.793

Sep082003_182121, Test VS2-114, Smoldering Laundry, !FOV, Trans

	PC1
_5900A	0.772
_7665A	0.933
_10500A	0.722
Ref_IR	0.901

Sep182003_133353, Test VS2-120, Flaming Trash Can, !FOV, Trans

	PC1	PC2
_5900A	0.059	-0.797
_7665A	0.926	-0.048
_10500A	0.923	0.101
Ref_IR	0.104	0.787

Sep182003_141133, Test VS2-121, Flaming Trash Can, FOV, Trans

	PC1	PC2
_5900A	0.966	-0.153
_7665A	0.984	0.077
_10500A	0.083	0.887
Ref_IR	-0.150	0.856

Sep232003_145302, Test VS2-126 (subsitute for VS2-223), Smoldering Cables, FOV, !Trans

	PC1	PC2
_5900A	0.923	0.000
_7665A	0.946	0.000
_10500A	0.719	0.000
Ref_IR	0.000	1.000

Sep242003_100748, Test VS2-131, People Working, ? FOV, !Trans

	PC1	PC2	PC3	PC4
_5900A	0.000	1.000	0.000	0.000
_7665A	0.000	0.000	1.000	0.000
_10500A	0.000	0.000	0.000	1.000
Ref_IR	1.000	0.000	0.000	0.000

Sep242003_104803, Test VS2-133, Aerosol Spray, ? FOV, !Trans

	PC1	PC2	PC3
_5900A	0.758	0.000	0.000
_7665A	0.758	0.000	0.000
_10500A	0.000	0.000	1.000
Ref_IR	0.000	1.000	0.000

Sep242003_140145, Test VS2-136, Burnt Toast, !FOV, !Trans

	PC1	PC2
_5900A	0.942	0.000
_7665A	0.938	0.000
_10500A	0.000	1.000

Ref_IR	0.153	0.000

Sep242003_144239, Test VS2-137, Welding, FOV, !Trans

	PC1	PC2
_5900A	0.849	0.000
_7665A	0.964	0.000
_10500A	0.948	0.000
Ref_IR	0.000	1.000

Sep252003_065636, Test VS2-141, Sunlight, !FOV, !Trans

	PC1	PC2
_5900A	0.859	0.000
_7665A	0.830	0.000
_10500A	0.779	0.000
Ref_IR	0.000	1.000

Sep302003_082827, Test VS2-145, White Shirt Waving, ? FOV, !Trans

	PC1	PC2	PC3
_5900A	0.921	0.000	0.000
_7665A	0.921	0.000	0.000
_10500A	0.000	0.000	1.000
Ref_IR	0.000	1.000	0.000

Sep302003_103617, Test VS2-152, Toast, !FOV, !Trans

	PC1	PC2	PC3
_5900A	0.982	0.000	0.000
_7665A	0.982	0.000	0.000
_10500A	0.000	0.000	1.000
Ref_IR	0.000	1.000	0.000

Sep302003_132510, Test VS2-154, Welding (Stick), !FOV, !Trans

	PC1
_5900A	0.888
_7665A	0.955
_10500A	0.905
Ref_IR	0.644

Sep302003_134829, Test VS2-155, Cutting Steel, FOV, !Trans

	PC1	PC2
_5900A	0.261	-0.713
_7665A	0.927	-0.299
_10500A	0.960	0.002
Ref_IR	0.016	0.826

Sep302003_141409, Test VS2-156, Cutting Steel, !FOV, !Trans

	PC1	PC2
_5900A	0.465	-0.504
_7665A	0.937	-0.125
_10500A	0.955	0.031
Ref_IR	0.061	0.925

Sep302003_151718, Test VS2-158, Smoldering Monitor, !FOV,!Trans

	PC1	PC2	PC3

```
_5900A      0.963   0.000   0.000
_7665A      0.963   0.000   0.000
_10500A     0.000   0.000   1.000
Ref_IR      0.000   1.000   0.000
```

D.0 APPENDIX D – ALGORITHM OPTIMIZATION TEST COLLECTIONS

D.1. Smoldering Source Test Collection

Table D.1 – Smoldering Source Test Collection

Filename	VS2	Date	Description	F/S/T/N[a]	In FOV?	Welding	Ignition
Aug062003_113622	41	8_6_03	Smoldering Laundry	S	No	No	11:36:52
Aug062003_121218	42	8_6_03	Smoldering Laundry	S	No	No	12:14:14
Aug062003_133432	43	8_6_03	Smoldering Laundry	S	Yes	No	13:35:47
Aug062003_160616	47	8_6_03	Smoldering Laundry	S	Yes	No	16:16:11
Aug182003_122930	48	8_18_03	Smoldering Laundry	S	Yes	No	12:31:49
Aug192003_144806	56	8_19_03	Smoldering Laundry	S	Yes	No	14:49:45
Aug202003_151703	64	8_20_03	Smoldering Laundry	S	Yes	No	15:19:20
Aug202003_163833	65	8_20_03	Smoldering Laundry	S	Yes	No	16:41:07
Aug212003_134530	70	8_21_03	Smoldering Laundry	S	Yes	No	13:47:45
Aug212003_143342	71	8_21_03	Smoldering Laundry	S	Yes	No	14:42:49
Aug252003_163128	76	8_25_03	Smoldering Laundry	S	Yes	No	16:32:49
Aug252003_173418	77	8_25_03	Smoldering Laundry	S	Yes	No	17:38:00
Aug262003_165704	84	8_26_03	Smoldering Laundry	S	Yes	No	16:58:34
Jul232003_101346	6	7_23_03	Smoldering Laundry	S	No	No	10:13:45
Jul232003_112202	7	7_23_03	Flaming Bedding	F	No	No	11:22:13
Jul232003_114831	8	7_23_03	Smoldering Cable	S	Yes	No	11:48:10
Jul232003_120118	9	7_23_03	Smoldering Cable	S	Yes	No	12:02:08
Jul232003_151943	10	7_23_03	Flaming Boxes w/ paper fill	F/S	Yes	No	15:21:17
Jul232003_161844	11	7_23_03	Smoldering Laundry	S	No	No	16:18:36
Jul242003_100156	15	7_24_03	Smoldering Cable	S	Yes	No	10:01:39
Jul242003_114817	17	7_24_03	Smoldering Laundry	S	No	No	11:48:02
Jul292003_095917	19	7_29_03	Flaming Boxes w/ paper fill	F/S	No	No	10:00:15
Jul292003_143521	27	7_29_03	Smoldering Cable	S	No	No	14:36:43
Jul292003_153654	28	7_29_03	Smoldering Cable	S	No	No	15:41:44
Jul292003_164001	29	7_29_03	Smoldering Cable	S	No	No	16:41:01
Oct232003_153300	164	10_23_03	Smoldering Cable	S	No	No	15:35:24
Oct232003_165200	165	10_23_03	Smoldering Cable	S	No	No	16:54:35
Oct242003_105005	169	10_24_03	Smoldering Mattress	S	No	No	10:53:16
Oct242003_131651	170	10_24_03	Smoldering Monitor	S	No	No	13:18:25
Oct242003_143443	171	10_24_03	Smoldering Monitor	S	No	No	14:39:02
Oct242003_164710	172	10_24_03	Smoldering Trash	S	No	No	16:48:02
Oct272003_143243	176	10_27_03	Smoldering Laundry	S	No	No	14:35:21
Oct282003_102659	179	10_28_03	Smoldering Wire	S	No	No	10:28:15
Oct282003_104335	180	10_28_03	Smoldering Wire	S	No	No	10:45:15
Oct282003_111335	181	10_28_03	Smoldering Circuit Board	S	No	No	11:15:06
Oct282003_151728	184	10_28_03	Smoldering Wire	S	No	No	15:18:19
Sep042003_153928	95	9_4_03	Smoldering Laundry	S	Yes	No	15:41:56
Sep052003_154457	102	9_5_03	Flaming Wood Crib	F/S	No	No	15:46:45
Sep082003_112713	107	9_8_03	Smoldering Laundry	S	No	No	11:27:57
Sep082003_141109	110	9_8_03	Smoldering Laundry	S	No	No	14:20:10

Filename	VS2	Date	Description	F/S/T/N[a]	In FOV?	Welding	Ignition
Sep082003_150133	111	9_8_03	Smoldering Laundry	S	Yes	No	15:02:15
Sep082003_182121	114	9_8_03	Smoldering Laundry	S	No	No	18:26:30
Sep182003_085705	115	9_18_03	Smoldering Cable	S	No	No	08:58:28
Sep182003_133353	120	9_18_03	Flaming Trash Can	F	No	No	13:38:35
Sep182003_141133	121	9_18_03	Flaming Trash Can	F/S	Yes	No	14:14:27
Sep232003_090939	122	9_23_03	Smoldering Cable	S	Yes	No	09:13:18
Sep232003_101834	123	9_23_03	Smoldering Cable	S	No	No	10:20:57
Sep232003_134307	125	9_23_03	Smoldering Cable	S	No	No	13:44:41
Sep232003_145302	126	9_23_03	Smoldering Cable	S	Yes	No	14:54:16
Sep232003_161651	127	9_23_03	Smoldering Cable	S	No	No	16:18:00
Sep242003_100748	131	9_24_03	People Working	N	N/A	No	10:08:13
Sep242003_104803	133	9_24_03	Spraying Aerosol	N	N/A	No	10:48:32
Sep242003_140145	136	9_24_03	Toast, Burnt	S/N	No	No	14:03:14
Sep242003_144239	137	9_24_03	Welding	N	No	Yes	14:43:12
Sep252003_065636	141	9_25_03	Sunlight	N	No	No	06:58:09
Sep302003_082827	145	9_30_03	Person Waving White Shirt	N	N/A	No	08:28:50
Sep302003_091125	149	9_30_03	Smoldering Monitor	S	No	No	09:21:54
Sep302003_103617	152	9_30_03	Toast	S/N	No	No	10:37:40
Sep302003_132510	154	9_30_03	Welding	N	No	Yes	13:26:48
Sep302003_134829	155	9_30_03	Cutting Steel	N	Yes	No	13:49:46
Sep302003_141409	156	9_30_03	Cutting Steel	N	No	No	14:14:50
Sep302003_151718	158	9_30_03	Smoldering Monitor	S	No	No	15:19:48

[a] F = Flaming Source. S = Smoldering Source. N = Nuisance Source. T = Transitioning Source.

D.2. Flaming Source Test Collection

Table D.1 – Flaming Source Test Collection

Filename	VS2	Date	Description	F/S/T/N[a]	In FOV?	Welding	Ignition
Aug052003_112112	31	8_5_03	Flaming Boxes	F	No	No	11:22:11
Aug052003_114916	32	8_5_03	Flaming Boxes	F	No	No	11:50:40
Aug052003_133409	33	8_5_03	Flaming Boxes	F	No	No	13:36:50
Aug052003_141001	34	8_5_03	Flaming Boxes	F	No	No	14:10:36
Aug052003_144959	35	8_5_03	Flaming Boxes	F	Yes	No	14:50:29
Aug052003_152027	36	8_5_03	Flaming Boxes	F	Yes	No	15:21:47
Aug052003_154953	37	8_5_03	Flaming Boxes	F	Yes	No	15:52:10
Aug052003_162409	38	8_5_03	Flaming Boxes	F	Yes	No	16:24:58
Aug062003_101630	39	8_6_03	Flaming Boxes	F	No	No	10:17:18
Aug062003_103808	40	8_6_03	Flaming Boxes	F	No	No	10:38:55
Aug062003_145617	44	8_6_03	Flaming Boxes	F	No	No	14:57:06
Aug062003_151530	45	8_6_03	Flaming Boxes	F	Yes	No	15:17:33
Aug062003_153939	46	8_6_03	Flaming Boxes	F	Yes	No	15:40:59
Aug182003_155126	50	8_18_03	Flaming Boxes	F	Yes	No	15:52:21
Aug192003_110012	52	8_19_03	Flaming Boxes	F	No	No	11:02:09
Aug192003_114132	53	8_19_03	Flaming Boxes	F	Yes	No	11:44:22
Aug192003_133824	54	8_19_03	Flaming Boxes	F	No	No	13:40:51
Aug192003_141257	55	8_19_03	Flaming Boxes	F	Yes	No	14:18:14
Aug202003_103624	58	8_20_03	Flaming Boxes	F	No	No	10:41:28
Aug202003_110858	59	8_20_03	Flaming Boxes	F	No	No	11:09:41

Filename	VS2	Date	Description	F/S/T/N[a]	In FOV?	Welding	Ignition
Aug202003_114428	60	8_20_03	Flaming Boxes	F	No	No	11:47:21
Aug202003_134155	61	8_20_03	Flaming Boxes	F	Yes	No	13:45:09
Aug202003_141353	62	8_20_03	Flaming Boxes	F	Yes	No	14:16:40
Aug202003_144214	63	8_20_03	Flaming Boxes	F	Yes	No	14:44:17
Aug202003_151703	64	8_20_03	Smoldering Laundry	S	Yes	No	15:19:20
Aug212003_093641	66	8_21_03	Flaming Boxes	F	No	No	09:39:34
Aug212003_101836	67	8_21_03	Flaming Boxes	F	No	No	10:21:24
Aug212003_105131	68	8_21_03	Flaming Boxes	F	Yes	No	10:55:14
Aug212003_113427	69	8_21_03	Flaming Boxes	F	Yes	No	11:36:14
Aug252003_135812	73	8_25_03	Flaming Boxes	F	Yes	No	14:00:37
Aug252003_144059	74	8_25_03	Flaming Boxes	F	No	No	14:43:44
Aug252003_154653	75	8_25_03	Flaming Boxes	F	No	No	15:50:38
Aug252003_163128	76	8_25_03	Smoldering Laundry	S	Yes	No	16:32:49
Aug252003_173418	77	8_25_03	Smoldering Laundry	S	Yes	No	17:38:00
Aug262003_114200	78	8_26_03	Flaming Boxes	F	No	No	11:46:11
Aug262003_133917	79	8_26_03	Flaming Boxes	F	No	No	13:41:47
Aug262003_141539	80	8_26_03	Flaming Boxes	F	No	No	14:18:53
Aug262003_144701	81	8_26_03	Flaming Boxes	F	Yes	No	14:50:53
Aug262003_151717	82	8_26_03	Flaming Boxes	F	Yes	No	15:20:02
Aug262003_165704	84	8_26_03	Smoldering Laundry	S	Yes	No	16:58:34
Aug272003_115709	85	8_27_03	Flaming Boxes	F	No	No	12:01:26
Aug272003_132940	86	8_27_03	Flaming Boxes	F	No	No	13:34:04
Aug272003_135910	87	8_27_03	Flaming Boxes	F	Yes	No	14:02:27
Aug272003_144520	88	8_27_03	Flaming Boxes	F	Yes	No	14:29:52
Jul232003_112202	7	7_23_03	Flaming Bedding	F	No	No	11:22:13
Jul232003_151943	10	7_23_03	Flaming Boxes	F	Yes	No	15:21:17
Jul242003_093845	14	7_24_03	Flaming Bedding	F	No	No	09:39:00
Jul242003_111131	16	7_24_03	Flaming Boxes	F	Yes	No	11:11:50
Jul242003_162236	18	7_24_03	Flaming Bedding	F	No	No	16:32:38
Jul292003_095917	19	7_29_03	Flaming Boxes	F	No	No	10:00:15
Jul292003_103533	20	7_29_03	Flaming Boxes	F	No	No	10:36:24
Jul292003_110022	21	7_29_03	Flaming Boxes	F	No	No	11:01:03
Jul292003_112451	22	7_29_03	Flaming Boxes	F	No	No	11:25:34
Jul292003_114932	23	7_29_03	Flaming Boxes	F	Yes	No	11:51:31
Jul292003_121613	24	7_29_03	Flaming Boxes	F	Yes	No	12:16:57
Jul292003_124353	25	7_29_03	Flaming Boxes	F	Yes	No	12:45:34
Jul292003_130544	26	7_29_03	Flaming Boxes	F	Yes	No	13:06:54
Oct022003_104335	160	10_2_03	Flaming Boxes	F	No	No	10:45:55
Oct232003_134005	161	10_23_03	Flaming Boxes	F	No	No	13:52:02
Oct232003_142211	162	10_23_03	Flaming Boxes	F	No	No	14:25:03
Oct232003_145825	163	10_23_03	Flaming Boxes	F	No	No	15:00:02
Oct232003_153300	164	10_23_03	Smoldering Cable	S	No	No	15:35:24
Oct232003_165200	165	10_23_03	Smoldering Cable	S	No	No	16:54:35
Oct242003_082138	166	10_24_03	Flaming Boxes	F	No	No	08:23:47
Oct242003_105005	169	10_24_03	Smoldering Mattress	S	No	No	10:53:16
Oct242003_131651	170	10_24_03	Smoldering Monitor	S	No	No	13:18:25
Oct242003_143443	171	10_24_03	Smoldering Monitor	S	No	No	14:39:02
Oct242003_164710	172	10_24_03	Smoldering Trash	S	No	No	16:48:02
Oct272003_143243	176	10_27_03	Smoldering Laundry	S	No	No	14:35:21
Oct282003_104335	180	10_28_03	Smoldering Wire	S	No	No	10:45:15
Oct282003_111335	181	10_28_03	Smoldering Circuit Board	S	No	No	11:15:06
Sep042003_114345	92	9_4_03	Flaming Boxes	F	No	No	11:45:45

Filename	VS2	Date	Description	F/S/T/N[a]	In FOV?	Welding	Ignition
Sep042003_121700	93	9_4_03	Flaming Boxes	F	Yes	No	12:18:34
Sep042003_124841	94	9_4_03	Flaming Boxes	F	Yes	No	12:51:44
Sep052003_112355	97	9_5_03	Flaming Boxes	F	No	No	11:25:43
Sep052003_131040	98	9_5_03	Flaming Boxes	F	No	No	13:12:40
Sep052003_135733	99	9_5_03	Flaming Boxes	F	No	No	13:59:30
Sep052003_143613	100	9_5_03	Flaming Boxes	F	No	No	14:39:17
Sep052003_150818	101	9_5_03	Flaming Boxes	F	Yes	No	15:10:21
Sep052003_154457	102	9_5_03	Wood Crib	F/S	No	No	15:46:45
Sep082003_094949	104	9_8_03	Flaming Boxes	F	Yes	No	09:53:09
Sep082003_102439	105	9_8_03	Flaming Boxes	F	No	No	10:25:35
Sep082003_105812	106	9_8_03	Flaming Boxes	F	No	No	10:59:42
Sep182003_095234	116	9_18_03	Flaming Trash Can	F	Yes	No	10:00:34
Sep182003_103915	117	9_18_03	Flaming Trash Can	F	Yes	No	10:42:35
Sep182003_110123	118	9_18_03	Flaming Trash Can	F	No	No	11:08:30
Sep182003_114035	119	9_18_03	Flaming Trash Can	F	No	No	11:42:54
Sep182003_133353	120	9_18_03	Flaming Trash Can	F	No	No	13:38:35
Sep182003_141133	121	9_18_03	Flaming Trash Can	F	Yes	No	14:14:27
Sep232003_145302	126	9_23_03	Smoldering Cable	S	Yes	No	14:54:16
Sep242003_100748	131	9_24_03	People Working	N	N/A	No	10:08:13
Sep242003_104803	133	9_24_03	Spraying Aerosol	N	N/A	No	10:48:32
Sep242003_140145	136	9_24_03	Toast, Burnt	S/N	No	No	14:03:14
Sep242003_144239	137	9_24_03	Welding	N	No	Yes	14:43:12
Sep252003_065636	141	9_25_03	Sunlight	N	No	No	06:58:09
Sep302003_082827	145	9_30_03	Person Waving White Shirt	N	N/A	No	08:28:50
Sep302003_103617	152	9_30_03	Toast	S/N	No	No	10:37:40
Sep302003_132510	154	9_30_03	Welding	N	No	Yes	13:26:48
Sep302003_134829	155	9_30_03	Cutting Steel	N	Yes	No	13:49:46
Sep302003_141409	156	9_30_03	Cutting Steel	N	No	No	14:14:50

[a] F = Flaming Source. S = Smoldering Source. N = Nuisance Source. T = Transitioning Source.